Research on bearing-only positioning and dynamic adjustment of UAV based on azimuth angle

Jiapei Chen, Yanxin Hu *

School of Materials and Energy, Guangdong University of Technology, Guangzhou, China, 510006

* Corresponding Author Email: cjp15113620192@163.com

Abstract. With the development of UAV application technology, multi-UAV cooperative operation has been applied to all walks of life, and the application of UAV bearing-only passive location technology also has an important impact. Based on the experimental data provided by the 2022 National College Students' Mathematical Contest in Modeling, this paper locates and adjusts the UAV with slight deviation on the circumference through the azimuth information. By using the geometric relationship between UAVs and the loop algorithm to define the small step size and distance threshold, the micro-dynamic adjustment model is established. Firstly, two UAVs, No.00 and No.01, are selected as the UAVs transmitting information on the center and circumference of the circle, respectively, to locate and adjust the adjacent UAVs. After that, an adjusted UAV adjacent to the UAV to be adjusted is added as the information UAV. At each time, the No.00 and No.01 and an adjusted UAV adjacent to the UAV to be adjusted are selected as the launch information UAV. The radial distance is adjusted first and then the circumferential distance is adjusted, and the positioning information is known in real time according to the direction angle. In this way, the UAV on the circumference is uniformly distributed on the circumference, and finally reaches the ideal position.

Keywords: UAV, Direction angle positioning, piecewise adjustment, dynamic adjustment model.

1. Introduction

With the rapid development of intelligent control technology and wireless communication technology, UAV technology has also matured, and UAV applications are becoming more and more popular. It is no longer difficult for multiple UAVs to rely on wireless communication for formation control [1]. At present, the ranging and positioning method based on laser range finder is a common, simple and accurate positioning method in recent years. However, this active positioning method will radiate electromagnetic waves to the outside world in actual positioning, which is easy to expose the position of the UAV itself and is easily disturbed by external factors, resulting in the exposure of UAV communication information and the disorder of interaction between UAVs. Therefore, the use of passive location technology is of great significance [2, 3]. Under this current demand, the formation flight of UAV clusters needs to keep electromagnetic silence as much as possible and reduce the emission of electromagnetic wave signals to the outside world. In this paper, the method of bearing-only passive location is used to adjust the position of the UAV, that is, several UAVs in the formation transmit signals and the remaining UAVs receive signals passively. The direction angle information is extracted for positioning, and then the position of the UAV is adjusted to realize the passive location of multiple UAVs based on the direction angle.

2. materials and methods

2.1. Data sources and characteristics

The research data of this paper comes from the 2022 National College Students ' Mathematical Modeling Contest [4]. According to the formation requirements, at the same height or plane, one UAV is located in the center of the circle, and the other nine UAVs are evenly distributed on the circle with a radius of 100 m. When the position of the UAV at the initial moment is slightly deviated, the direction information is adjusted multiple times. Each time, the UAV numbered 00 and up to 3

UAVs on the circumference are selected to transmit the signal. The remaining UAVs are adjusted to the ideal position required by the formation according to the received direction information, so that 9 UAVs are finally evenly distributed on a certain circumference. On the basis of this topic, as shown in Table 1, this paper uses the given polar coordinate data table to locate and adjust a circular formation of UAVs with a slight deviation in position. The position of the UAV is adjusted only according to the received direction information, and a reasonable UAV position adjustment scheme is given.

Table 1. Initial position of UAV

UAV number	polar coordinate (m,◦)
00	(0, 0)
01	(100, 0)
02	(98, 40.10)
03	(112, 80.21)
04	(105, 119.75)
05	(98, 159.86)
06	(112, 199.96)
07	(105, 240.07)
08	(98, 280.17)
09	(112, 320.28)

2.2. Method introduction

Firstly, the coordinates of 10 points in the initial position of the UAV in Table 1 are visualized, and the circular contour and the position of the ideal UAV are drawn as a reference. The visualized coordinate diagram of the initial position of the UAV is shown in Figure 1.

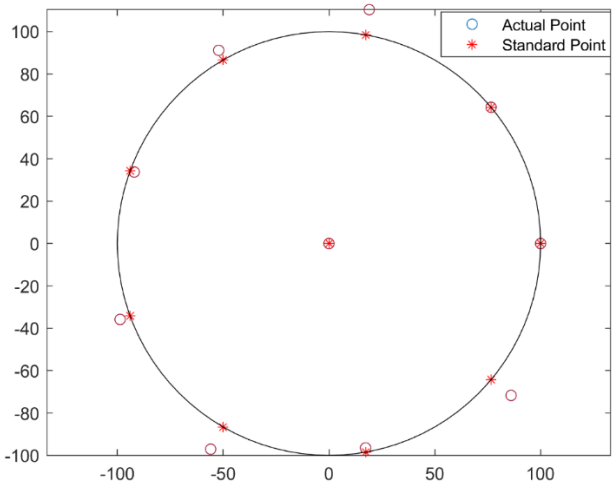


Figure 1. Visual coordinate diagram of UAV initial position

It is found that the nine UAVs numbered 1-9 are roughly distributed near the circumference of radius $R = 100$. After the given data, there are two UAVs that are not completely on the R = 100 circle. Directly selecting multiple UAVs as the transmitting signal UAV will increase the complexity of the problem. In order to simplify the problem and use the UAV transmitting signal as little as possible, a piecewise dynamic adjustment scheme model is developed. The circle with radius of 100 and number 00 is selected as the target graph. The step size of the UAV is set to 0.01 m each time, and the critical threshold of the UAV close to the circumference distance is calculated. The UAV can move linearly along the radial direction, and the UAV transmitting the signal during the adjustment process is always stationary relative to the ground. The undetermined UAV re-accepts the direction information after each fine-tuning until it reaches the threshold. At this time, it is considered that the UAV has reached the circumference [5].

The first step of the model is to select the signal emitted by the No.00 UAV and the No.01 UAV in the center of the circle, adjust the No.02 UAV, and adjust the No.02 UAV to the circumference of the No.01 UAV. The second step is to select No.00,01 and an adjusted UAV adjacent to the UAV to be adjusted as the launch information UAV, traverse No.03-09 seven UAVs, and first adjust the radial distance of each position slightly deviated UAV. The third step is to adjust the circumferential distance of the numbered 03-09 drone counterclockwise on the basis of the second step. The model flow chart is shown in Figure 2.

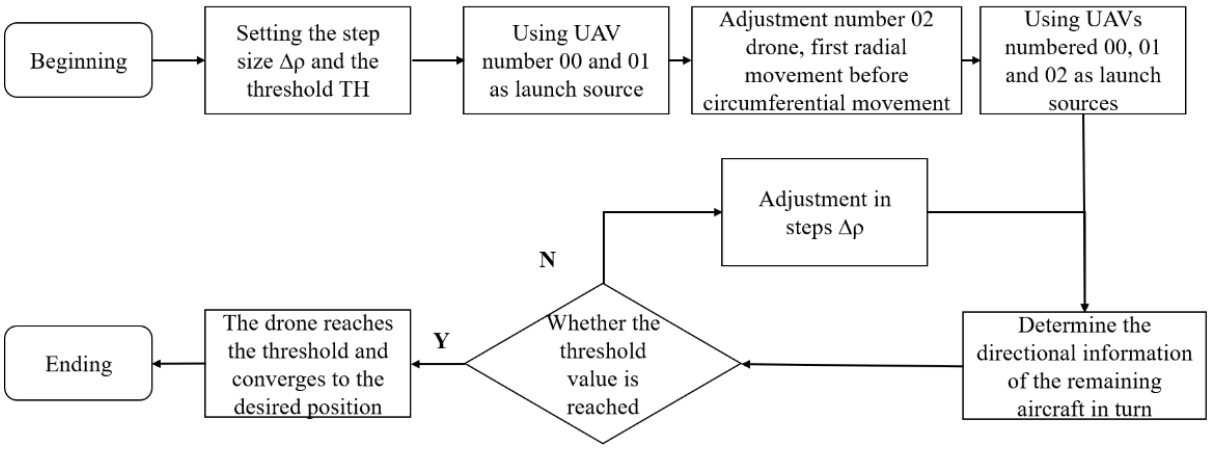


Figure 2. Model flow chart

The model proposed in this paper makes the positioning and adjustment of the UAV procedural and controllable. The underlying principles of the adjustment procedure are the vector method, the cosine theorem and the application of analytic geometry, and the procedure runs fast.[6] While adjusting the drone, it is also possible to know the direction information of the drone in real time, and thus the location information of the drone.

2.3. Model Evaluation Metrics

The results of the model are visualized in terms of the optimal azimuth and the coordinates of each UAV. The final threshold of this paper can be 0, which means that the results of this paper can be obtained as a circular formation with a uniform distribution of UAV swarms. In addition, this paper uses three UAVs transmitting signals at a time with a minimum number of UAVs transmitting signal concepts to achieve pure directional passive precise positioning of UAVs [7].

3. Model building and solving

3.1. Establishing a slightly deviating UAV microdynamic adjustment scheme

Determine the initial threshold TH and step size $\Delta\rho$ of the slightly deviated UAV and the final adjustment of the UAV to the ideal circumference with a circumference radius of 100m.

$$\Delta\rho = 0.01 \tag{1}$$

$$TH = \sqrt{x^2 + y^2} - R^2 \tag{2}$$

Among them, $\Delta\rho = 0.01$ is the set step size, that is, the distance that the UAV adjusts to the ideal circular contour each time according to the step size [8]. The distance of each adjustment is very small, and the gap pause time is very small, that is, the UAV continuously updates the threshold and adjusts the direction information during flight. $TH = \sqrt{x^2 + y^2} - R^2$ is the length of the distance circle, which is called the threshold, that is, the critical value of the slightly deviated UAV close to the ideal circle contour [9].

3.2. Adjust number 02 UAV

The first step of the model is to determine the selection of the No.00 UAV in the center of the circle and the No.01 and No.02 UAV as the emission signal, adjust the No.02 UAV, and adjust the No.02 UAV to the circumference of the No.01 UAV. First, the No.02 UAV is close to the ideal circular contour on the straight line where the radius is located [10]. The moving direction is divided into near-center direction and far-center direction. When $\angle \mathrm{ABO} > 70°$, the UAV to be adjusted is in the circumference, and the adjustment moves to the telecentric direction; when $\angle \mathrm{ABO} < 70°$, the UAV is adjusted to move in the near center direction outside the circumference. The cyclic iterative adjustment is along the radial motion, and the direction information is received again after the adjustment, and the threshold TH is updated once. Finally, it is judged whether the latest threshold is the set ideal threshold. The closest to 0 ends the cycle and jumps out of the latest direction information. At this time, the position slightly deviates from the UAV on the ideal circular contour.

Then, make circumferential adjustment. When the UAV is adjusted to the circumference, the moving direction is determined according to the direction angle. When $\angle \mathrm{ABO} > 70°$, the UAV to be adjusted moves counterclockwise; when $\angle \mathrm{ABO} < 70°$, the UAV to be adjusted moves clockwise [11]. The adjustment diagram of No. 02 UAV is shown in Figure 3.

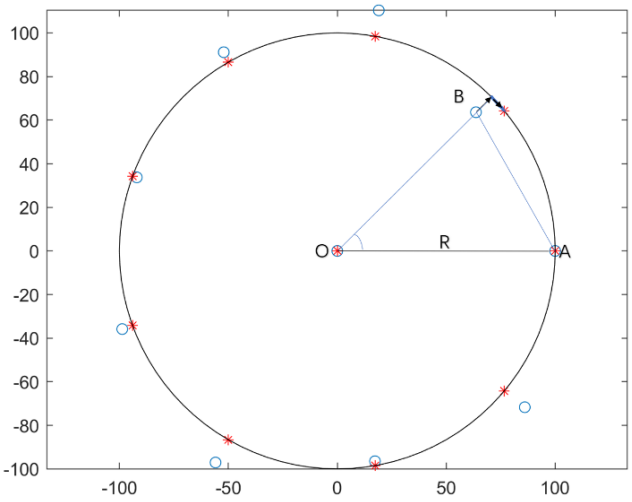


Figure 3. No. 02 UAV adjustment step diagram

3.3. Adjust the position of the remaining drones in turn

Select the number of 00, 01 and an adjusted UAV adjacent to the UAV to be adjusted as the launch information UAV, traverse the seven UAVs of 03-09, and first adjust the radial distance of the UAV with a slight deviation of each position [12]. When $\angle BOC > \frac{\left[\pi-\frac{2\pi}{9}(k-1)\right]}{2}$, the UAV to be adjusted is in the circumference, and the adjustment moves to the far center direction. When $\angle BOC < \frac{\left[\pi-\frac{2\pi}{9}(k-1)\right]}{2}$, the UAV to be adjusted is outside the circumference, and the adjustment moves in the near-center direction. At this time, the direction information of the UAV is determined according to the direction angles $\angle ACO$、$\angle BCA$ and $\angle BOC$ [13].

$$\vec{C}\vec{O} = (-\mathrm{x}, -\mathrm{y}) \tag{3}$$

$$\vec{C}\vec{A} = (a_2 - x, b_2 - y) \tag{4}$$

$$\vec{C}\vec{B} = (a_1 - x, b_1 - y) \tag{5}$$

$$\alpha_1 = ar\cos\left(\frac{\vec{C}\vec{O}\cdot\vec{C}\vec{B}}{|CO|\cdot|CB|}\right) \tag{6}$$

$$\alpha_2 = ar\cos(\frac{\vec{CA}\cdot\vec{CB}}{|CA|\cdot|CB|}) \tag{7}$$

$$\alpha_3 = ar\cos(\frac{\vec{CO}\cdot\vec{CA}}{|CO|\cdot|CA|}) \tag{8}$$

The third step is the iteration on the circumference based on the second step. The position slightly deviated UAV moves on the ideal circular contour according to the change of the corresponding direction angle [14]. At this time, in order to avoid the reverse movement of the drone, the order is adjusted one by one. At this time, the number 00 and 01 are selected as the launch information drone, and the circumferential distance of the number 03-09 drone is adjusted in turn. When $\angle AOC > \frac{\left[\pi-\frac{2\pi}{9}(k-1)\right]}{2}$, the UAV to be adjusted moves counterclockwise; when $\angle AOC < \frac{\left[\pi-\frac{2\pi}{9}(k-1)\right]}{2}$, the UAV to be adjusted moves the UAV clockwise until it is evenly distributed on the target circumference, and the model jumps out of the loop. The adjustment steps of the No.03 UAV are shown in Figure 4.

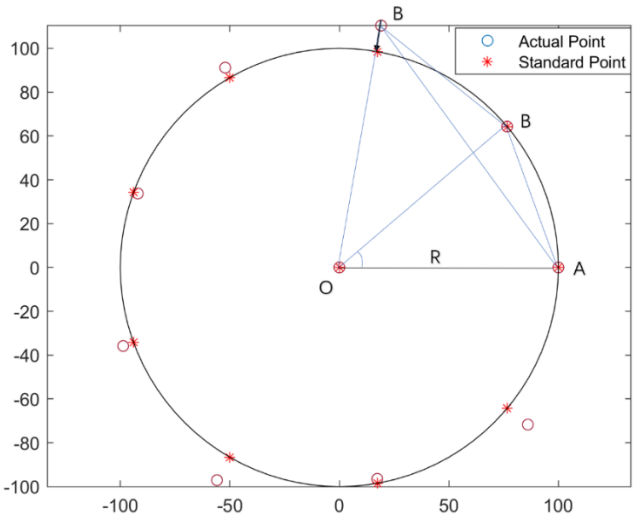


Figure 4. No. 03 UAV adjustment step diagram

4. Conclusions

In modern and future development, the rapid development of information technology has effectively promoted the innovation and development of modern UAV technology, and has been widely used in more and more fields. In response to the needs of all walks of life, the application technology of UAV is also pursuing digitization, real-time and precision. In this paper, the formation flight of UAV cluster should be carried out to reduce the need for external emission of electromagnetic wave signals, maintain electromagnetic silence as much as possible, and still achieve high-precision positioning of UAVs and maintain formation formation. In this paper, the method of bearing-only passive location is used to adjust the position of UAV, combined with vector method, cosine theorem and analytic geometry method. According to the initial UAV position, several UAVs in the formation are selected to transmit signals, and the remaining UAVs passively receive signals, from which the direction angle information is obtained for positioning, and then the position of the UAV is adjusted. The model proposed in this paper makes the positioning and adjustment of UAV procedural and controllable, and the program runs quickly. Finally, the threshold difference between the adjustment position and the ideal position is between 0 and 0.01 meters. The model is reasonable and the result is accurate. The model has good real-time performance and robustness. Compared with visual module, three-dimensional technology positioning and laser technology, the program runs fast and has good real-time performance. It has high application and reference value, and can be applied to real-time precise positioning without GPS signal, indoor and so on.

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