UAV Multi-target Tracking Based on the Principle of Information Concentration

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Abstract.
At present, unmanned aerial vehicle (UAV) target tracking technology mainly focuses on single target tracking, rather than single UAV tracking multiple targets. Based on the principle of information concentration and numerical calculation, a new trajectory prediction algorithm for UAV tracking is proposed in order to improve the execution efficiency of target tracking. The principle of information concentration which uses the set of tracking objects and numerical calculation method are used to determine the current position information of UAV. Considering the real motion form of UAV, Kalman filter algorithm is used to smooth the tracking position information, which improves the robustness of the algorithm. In addition, since the complexity of the algorithm is not affected by the number of tracking targets, the new multi-target tracking algorithm can be applied to the engineering background with more targets.

Keywords: Target Tracking, Information Concentration, Multi-circle Intersection, UAV, Kalman Filter

1. INTRODUCTION

UAV is developing towards high survival rate, low-cost and low loss [1]. Based on this, it can be used for target tracking and the tracking information can be integrated into the network to realize resource sharing and reduce the cost of target tracking.

In addition, L. Fan used CCCP algorithm to overcome the problem of high energy consumption of UAV in data transmission [2], which further promoted the development of UAV target tracking field.

At present, UAV target tracking technology mainly focuses on target location. However, there are few researches on single UAV tracking multiple targets.

Target tracking technologies mainly include correlation filtering and deep learning [3]. And the technologies can be roughly divided into region-based methods, tracking based on motion estimation and tracking based on target features [4].

Among them, the tracking method based on motion estimation is the most common one. It mainly integrates the basic motion information of the targets and applies Kalman filter to achieve the tracking. Therefore, to explore a new feasible UAV tracking trajectory prediction method is the focus of UAV research.

1.1. Application scenarios

This research takes UAV tracking target vessels as the engineering background. Specifically, the background is that there are some working vessels and each vessel is in accordance with the specific motion law.

In order to reduce the energy consumption rate of working vessels, it is not considered to integrate each vessel into the network for data exchange. Therefore, a single UAV is used to track multiple working vessels.

When the working vessel deviates from the working track or the surrounding environment is bad, an alarm is issued through the UAV. Then, the working status of all vessels are sent to the switchboard in real time.

In addition, the algorithm can also play an important role in rescue and relief work, such as the delivery of supplies and rescue equipment, the command of rescue work and so on [5,6,7].

1.2. Premises and assumptions

Based on the above engineering background, two reasonable assumptions are proposed in this study, which are the application conditions of the new UAV tracking trajectory prediction algorithm in this study.

- It is assumed that the position information of the working vessels with a certain accuracy can be obtained. Besides, the sampling frequency of the sensor is large enough so that the UAV can obtain the position information with no obvious time lag. With the rapid development of radar technology and UAV aerial photography, target tracking technology is developing in the direction of stronger real-time performance. Besides, the Kalman filter modified by neural network can further improve the radar track tracking effect [8].
- Consider only the case where a single UAV can track all working vessels. Before the UAV is put into production, we can investigate whether the UAV can complete the tracking of all the working vessels in the whole movement process through the simulation method using the new UAV tracking trajectory prediction algorithm proposed in this study. If complete tracking is not possible, a sensor with a higher detection range or a lower

UAV flight altitude is considered to improve the detection range. Besides, particle swarm optimization algorithm can be used to solve the cooperative tracking problem of multiple UAVs [9].

2. METHODOLOGY

Taking UAV target tracking as the working background, this study proposes a new UAV tracking trajectory prediction algorithm based on the principle of information concentration and Kalman filter.

This study discusses the feasibility and convenience of the algorithm. The algorithm is not limited by the number of targets and can predict the tracking trajectory of UAV using the location information of the targets.

Considering the real motion form of UAV, this study uses Kalman filter algorithm to smooth the tracking trajectory of UAV and optimize its trajectory, making the predicted trajectory more consistent with the physical reality.

2.1. Information concentration

Based on the principle of information concentration [10,11], Multi-circle intersection is a simple target estimation algorithm.

This algorithm calculates the intersection of multiple circles from the perspective of numerical calculation. Its complexity is obviously lower than that of geometric intersection method. X. Cui et al. proposed a fast algorithm for target tracking in binary sensor networks by using the three-circle intersection algorithm [12].

Multi-circle intersection not only makes the target tracking algorithm simple and fast, but more importantly, the algorithm complexity is not limited by the number of targets. Therefore, the UAV can track multiple targets at the same time.

Based on this, the multi-circle intersection method can be used to predict UAV tracking trajectory from the perspective of numerical calculation.

2.2. Kalman filter

Kalman filter is an algorithm that seeks a set of recursive estimation based on the minimum mean square error (MSE) as the best estimation criterion [13].

The basic idea is to update the estimate of state variables by using the estimate value of the previous moment and the observation value of the present moment. Then, the estimate value of the present moment can be obtained. At present, it is widely used in control, communication and UAV fields.

In addition, the GM-PHD filter, which has a similar calculation idea to Kalman filter, predicts the position of the current moment according to the estimated value of the last moment and the observed value of the present moment in the tracking of spatial close-range targets [14].

Considering that Kalman filter has the characteristics of unbiased, stable, optimal, small computation and real-time calculation, the position and velocity of the target can be predicted more accurately [15], Kalman filter algorithm is used in this study to optimize the trajectory of UAV.

3. INFORMATION CONCENTRATION

This paper takes three targets tracked by a single UAV as an example and the schematic diagram is shown in Fig. 1. It is assumed that A_1, A_2 and A_3 are three targets with coordinates of (x_1, y_1), (x_2, y_2) and (x_3, y_3) respectively. The detection radius of UAV is r, and the location set of the UAV that can detect three targets at the same time is M.

If the set M is empty or too small, expanding the UAV search radius or lowering the UAV flight altitude can be used to increase the searchable area. However, this study only considers the case when M is not empty.

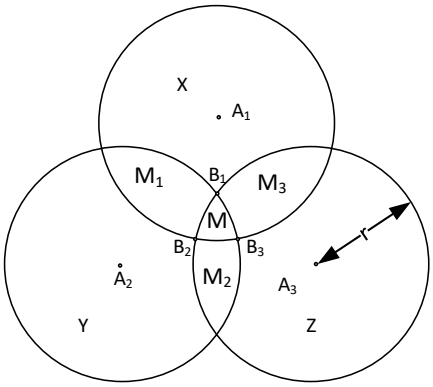


Fig. 1 Schematic diagram of multi-circle intersection

For any point P (x, y) in set M, the following relation is satisfied, as shown in Eq. (1).

$$\forall P(\mathrm{x},\mathrm{y}) \in M, \| \vec{P} - \vec{A}_i \| < r \tag{1}$$

In this study, the set M is obtained by numerical calculation method. Compared with the method of solving binary quadratic equations, the former is more convenient to calculate. Using the numerical calculation method, the complexity of calculation is not affected by the number of targets.

The primary goal of solving the binary quadratic equation is to determine the three vertices of the set M. Taking point B_1 as an example. First, set the coordinates of B_1 as (x_b, y_b). Then the coordinates of B_1 can be solved according to Eq. (2).

$$\begin{cases} (x_b - x_1)^2 + (y_b - y_1)^2 < r^2 \\ (x_b - x_2)^2 + (y_b - y_2)^2 = r^2 \\ (x_b - x_3)^2 + (y_b - y_3)^2 = r^2 \end{cases} \tag{2}$$

The calculation cost is high and it is difficult to implement it on UAV by solving the equation (2) directly and getting accurately results. Therefore, this study takes multi-circle intersection algorithm (as shown in the equation (1)) as the theoretical basis.

The specific algorithm flow is as follows: Firstly, the point set X+M_1+M is determined by considering the

target A_1, then the point set M_1+M is determined by considering the target A_2 in the point set X+M_1+M. Finally the point set M is determined by considering the target A_3 in the point set M_1+M. Thus, the point set M is obtained.

The algorithm complexity is $O(N^2)$. It is more convenient than the floating-point operation of solving the binary quadratic equation. The numerical algorithm can be extended to multiple (>3) targets tracking problems by iterating formula 1.

After the point set M is obtained, in order to give a more reasonable UAV tracking position point (x_c, y_c), the operation of taking geometric center point of point set M is considered by using Eq. (3), where n is the number of points in point set M.

$$\forall P_i(x_i, y_i) \in M, x_c = \frac{1}{n}\sum_{i=1}^{n} x_i, y_c = \frac{1}{n}\sum_{i=1}^{n} y_i \quad (3)$$

So far, a target tracking algorithm based on the principle of information concentration is obtained. The preimage of this operator is the position information of all vessels and the image is the position point of UAV. The structure of the multi-circle intersection algorithm is shown in Fig. 2.

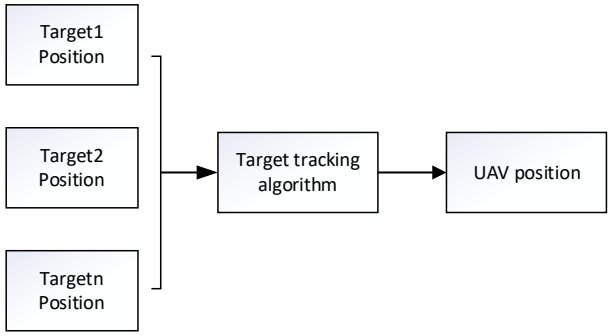


Fig. 2 Structure of target tracking algorithm based on the principle of information concentration

Considering that it is difficult to obtain the tracking efficiency of UAV tracking multiple targets according to the point set M, the convex hull of point set M is obtained by a certain method. And the method which this study uses is the two-dimensional convex hull rapid generation algorithm [16].

The specific method is as follows. Firstly, select the points on the boundary of set M. Then eight special points are selected on the boundary of M. The selection method of points is to divide the ordinate into four equal parts and each ordinate contains two points. The schematic diagram is as follows.

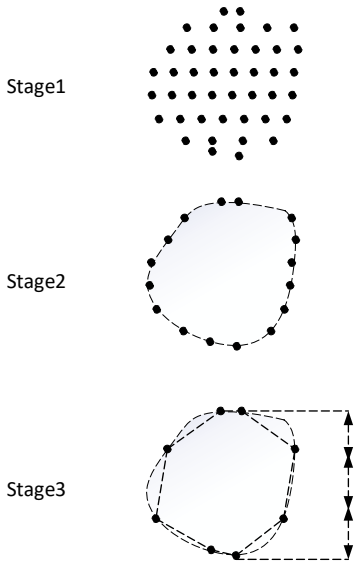


Fig. 3 Convex hull diagram

According to the convex octagon, the performance index of UAV tracking target can be determined, including tracking area, tracking direction, etc.

As for traceable area index, the area of the convex octagonal is calculated to approximate the area of M. The algorithm for calculating the area of a convex octagon is as follows.

First, choose a vertex P_1 freely. Starting from P_1 and ending from other vertices, line segments are formed respectively. Then sort these line segments by slope. Next, calculate the area of the triangle formed by the vertices and the two points in turn. Finally, add them up to get the convex octagonal area. Fig. 4 is the schematic diagram.

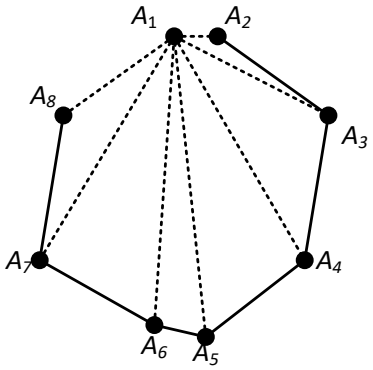


Fig. 4 Schematic diagram of area of convex octagon

As for how to get the tracking direction index, this study uses the following method. The line segment with the longest length is selected as the tracking direction of UAV among 28 lines formed by convex octagons. Fig. 5 is the schematic diagram.

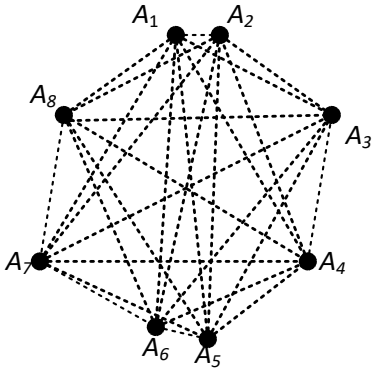


Fig. 5 Schematic diagram of longest string calculation

4. KALMAN FILTER FOR TRACK SMOOTHING

Firstly, the state equation and observation equation of stochastic linear discrete system need to be obtained. In this problem, the track needs to be smoothed. Therefore, the equation of state and observation equation are expressed as follows:

$$\begin{cases} x_t = Fx_{t-1} + Bu_t \\ z_t = Hx_t \end{cases} \quad (4)$$
$$F = 1, B = 0, H = 1$$

The time update and prediction update process of Kalman filter in linear discrete system are shown in Fig. 6.

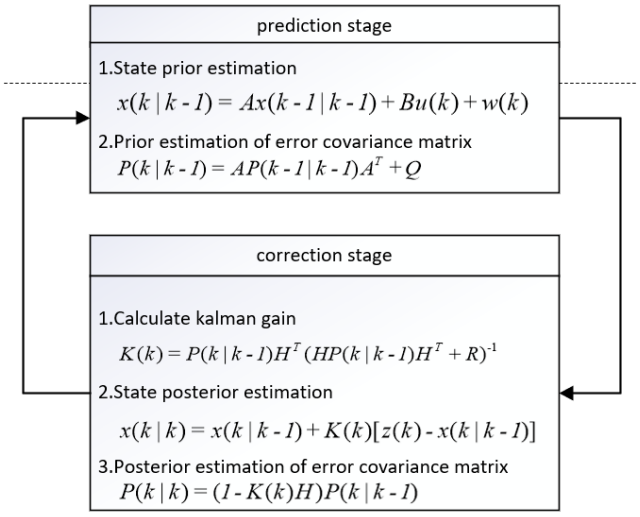


Fig. 6 Time update and prediction update process of Kalman filter

According to the equation (4) and 5 rules of Kalman filter, 5 equations of state update are sorted out, as shown in Eq. (5).

$$\begin{cases} x(k|k-1) = x(k-1|k-1) \\ P(k|k-1) = P(k-1|k-1) \\ K(k) = P(K|K-1)[P(K|K-1) + R]^{-1} \\ x(k|k) = x(k|k-1) + K(k)[z(k) - x(k|k-1)] \\ P(k|k) = [1 - K(k)]P(k|k-1) \end{cases} \quad (5)$$

Using the equation (5), $x(0)$ and $P(0)$, the estimated value of the state at each time can be obtained recursively. $P(0)$ can be 1 and $x(0)$ can be the position of the UAV at the beginning time.

Finally, an algorithm flow chart of single UAV tracking multiple targets based on the principle of information concentration is obtained.

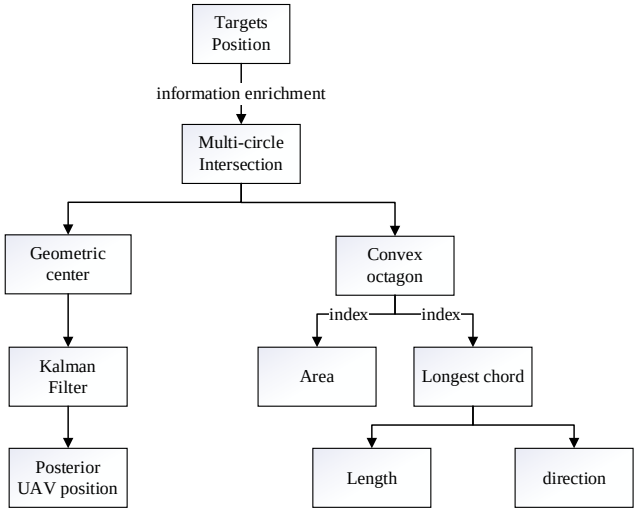


Fig. 7 The overall algorithm flow chart

5. EXPERIMENT RESULTS

5.1. Information concentration

The target tracking algorithm based on the principle of information concentration is realized in the form of simulation. The position information of the working vessel can be tracked in real time to determine the trajectory of the UAV. In the simulation, it is ensured that all targets can be tracked completely during the whole movement of UAV.

The blue dots represent UAV and the yellow dots represent working vessels. The results are shown in Figs 8-10. Fig. 8 is the diagram of the moment at t=0. Fig. 9 is the diagram of the moment at t=10. Fig. 10 is the diagram of the moment at t=20.

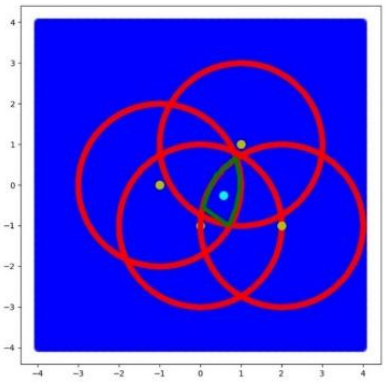


Fig. 8 UAV tracking effect diagram-t=0

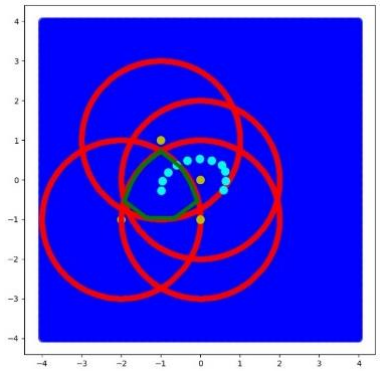


Fig. 9 UAV tracking effect diagram-*t*=10

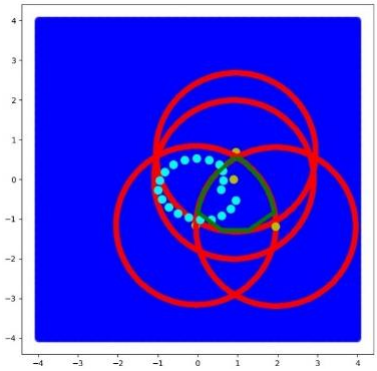


Fig. 10 UAV tracking effect diagram-*t*=20

The evaluation indexes of UAV tracking trajectory prediction efficiency are proposed, including three indexes. It is area of convex set formed by multi-circle intersection, maximum chord length and direction, as shown in Fig. 11.

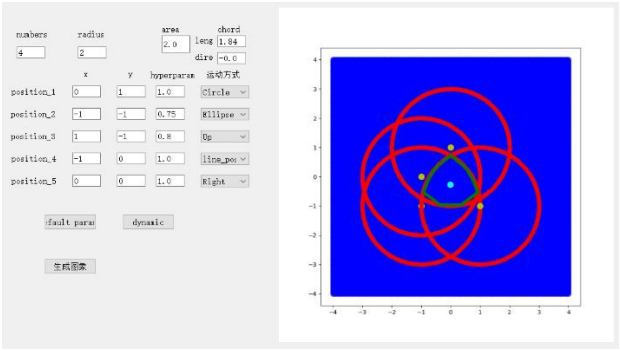


Fig. 11 simulation interface

The following is the motion form of the targets in the figure above. The motion form of target 1 is a circle which the center is (0,1) and the radius is 1. The motion form of target 2 is an ellipse which the short semi-major axis is 0.75 and the semi-major axis is 1. Target 3 moves upward and target 4 moves along a straight line which the slope is 1.

Then, it is the discussion of the three tracking indexes. The detection range of UAV can be adjusted adaptively according to the convex set area. And the tracking direction and speed can be determined according to the maximum chord and direction.

5.2. Other methods to find circle intersection

The methods for calculating the intersection of circles include floating-point arithmetic, geometric algorithm and numerical algorithm based on the principle of information concentration.

The floating-point algorithm is not considered because the calculation cost is too high due to the need to obtain the exact solution of the equation.

As for the geometric method, the main idea is as follows. Fig. 12 is the schematic diagram. Point A and B are the center point of the circles. Point C and D are the ends of the common string.

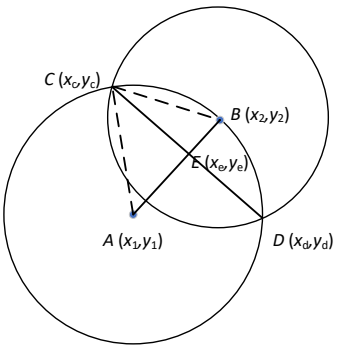


Fig. 12 Schematic diagram of geometric algorithm

Firstly, AE length is calculated according to the center and radius of the two circles. Secondly, the length of CE and the slope of the common string CD are obtained. Finally, the coordinates of C and D can be obtained using the above results. The specific calculation process is as follows.

$$\begin{cases} r_1^2 = AE^2 + CE^2 \\ r_2^2 = BE^2 + CE^2 \end{cases} \rightarrow$$

$$r_1^2 - r_2^2 = AB*(2AE - AB)$$

$$AE = \frac{r_1^2 - r_2^2 + AB^2}{2AB}$$

$$\begin{cases} x_e = x_1 + \frac{AE}{AB}(x_2 - x_1) \\ y_e = y_1 + \frac{AE}{AB}(y_2 - y_1) \end{cases}$$

$$K_1 = \frac{y_2 - y_1}{x_2 - x_1}, K_2 = -\frac{1}{K_1}$$

$$CE = DE = \sqrt{r_1^2 - AE^2}$$

$$\begin{cases} x_{c,d} = x_e \pm \frac{CE}{\sqrt{1 + K_2^2}} \\ y_{c,d} = y_e \pm \frac{(CE)K_2}{\sqrt{1 + K_2^2}} \end{cases}$$

However, the geometric method has obvious shortcomings. With the increase of the number of circles, the number of intersections to be calculated increases. Besides, the selection of common intersection vertices becomes more complicated.

Compared with the geometric method, the complexity of the numerical calculation algorithm is not affected by the number of targets. Besides, the whole detectable range of the UAV can be obtained, which provides the possibility to obtain tracking performance indicators later.

5.3. Kalman Filter for Track Smoothing

The following figure shows the UAV track comparison before and after Kalman filter is used. The green curve is the UAV track obtained without Kalman filter, and the red curve is the UAV track obtained by Kalman filter. It can be found that the original track can be smoothed and optimized by Kalman filter.

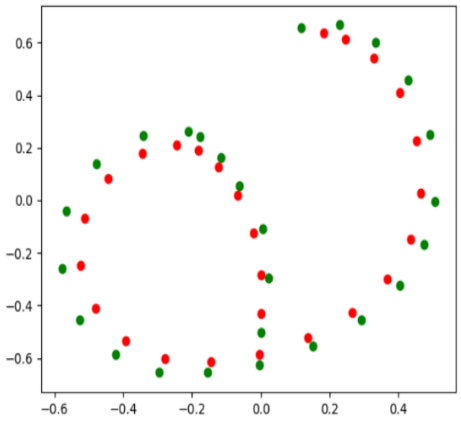


Fig. 13 Smoothing results of Kalman filtering

6. CONCLUSION

In this study, based on the background of single UAV tracking multiple targets, a UAV tracking trajectory prediction algorithm based on the principle of information concentration and numerical calculation method is proposed. Then, the UAV tracking trajectory is optimized by Kalman filter to conform to the physical reality.

On the one hand, the communication efficiency between the switchboard and the working vessel can be improved. The cost of receiving data can be reduced. On the other hand, there is no need to consider communication with the switchboard on the working vessel, as the status information of the working vessels is sent to the switchboard by UAV. Due to this, the working efficiency of the working vessel can be maximized.

This study takes specific engineering background as an example, so the application scenarios of this algorithm are limited. Besides, the feasibility and convenience of this algorithm in other scenarios need to be further verified.

In addition, this study only proposed the evaluation index of UAV tracking trajectory prediction efficiency. And further research needs to systematically explore more accurate UAV tracking trajectory prediction algorithm in single UAV or multiple UAV tracking scenarios.

Acknowledgements

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