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The Path Planning Algorithm Studying about UAV Attacks Multiple Moving Targets based on Voronoi Diagram

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Abstract

In order to solve the path planning problem about UAV attack multiple moving targets under dynamic environment, analytical method is proposed in this paper. Firstly, the Voronoi diagram method is used to create threat field, and the total planning cost is established. Then, the artificial potential field method and the dijkstra algorithm is improved and optimized respectively. For the track point outside the Voronoi diagram, the artificial potential field method is used to generate the local track. For the track point inside the Voronoi diagram, the dijkstra algorithm is used to track the moving target tracking along the side of Voronoi diagram, and the analytical method that UAV path planning method of moving target under dynamic environment is put forward. Finally, the simulation experiment is conducted, the result of simulation shows that the Voronoi diagram method can become complex airspace into division problems, the search space is reduced effectively, the time of planning is shorten, and the UAV real-time tracking and precision strikes against multiple moving targets can be resolved efficiently.

Keywords*: UAV; Voronoi diagram; artificial potential field method; dijkstra algorithm; multiple moving targets; dynamic path planning*

1. Introduction

Path planning as an important part of UAV combat system, the development of its technology has received the extensive attention of scholars both at home and abroad [2-3]. The path planning under static environment has made some research results [4-5]. The literature [4] proposed a real-time A * search based on a dynamic path planning algorithm for UAVs . The algorithm will combinate aircraft movement and the track search , track real-time planning based on the information available online , and improve the ability of UAV autonomous flight . The literature [5] pass the position relation between UAVs and threat, target and take sense of vision information as basis, proposed a method for real-time path planning of obstacle avoidance. However, with the growing complexity of the battlefield environment , the difficulty of UAV missions are increasing [1]. The path planning of static environment has been far not meet the actual need of the battlefield , so the UAV path planning in dynamic environment is increasingly becoming a hot research.. The literature [6-7] for path planning on problem UAV flying at low altitude sudden threat environment , gives the model predictive control algorithm based UAV avoid a collision with an obstacle occurs . The literature[8] based on real-time detect environmental information, real-time three-dimensional path planning algorithm is presented. This algorithm can real-time update threat data, fixed track line is affected, to obtain a new global optimal path. The literature [9] ensure that aircraft can generate more accurate instruction track dynamic environment, guide the aircraft flying in smaller deviation along the reference path, such as on-line path planning of the rolling optimization method is given. But considered in existing static under the threat of route

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planning, all can put the position, type and extent of the threat of consideration for the known stationary state, ignoring the dynamic environment of the uncertainty of threat and mobility. The literature [10] through analyze the threat types, and plan out the corresponding track, put forward the dynamic environment of unmanned aerial vehicle (uav) route planning method based on model predictive control, however the mobile threat at a constant speed motion, mobility is relatively simple, when the mobile threat mobility is more complicated when its application is limited. The literature [11] on the path planning problem for mobile threat of unmanned aerial vehicle (uav), is proposed based on a threat to the state prediction of model predictive control algorithm, based on the prediction of the mobile threat track planning a new track, etc. The literature [12] The LRTA* (learning Real-Time A*) algorithm combines the characteristics of the aircraft trajectory planning for each step made to reflect the real-time moving target , by expanding the scope of optimization within a limited period of time , to meet the real-time online request and feasible region can be effectively avoided . But, the algorithm needs within a larger range search , planning time will be longer . The literature [13] using the improved D* Lite search algorithm , designed a three-dimensional fast path planning method . The improved cost evaluation function , according to real-time information emerging threats and moving targets , the path planning constraints and improved search algorithm are combined to give a three-dimensional path planning method unmanned aircraft when moving ground targets . In existing UAV chase moving target track planning method, because the algorithm such as LRTA*, D* Lite planning for a long time, poor real-time performance, so it is difficult to meet the demand of the actual battlefield environment.

At present, the domestic and foreign unmanned aerial vehicle (uav) for fixed target track planning method research has made certain research results, the study of moving target is still in the exploratory stage, according to a single UAV attack moving targets more research literature reports yet. Single UAV attack moving target problem is not solved. This paper proposes a dynamic path planning method for multiple moving targets. First according to the distribution of known threats, constructs the threat the distribution of the Voronoi diagram. Then using artificial potential field method and the Dijkstra algorithm, to generate the shortest path, and further to find the optimal route of unmanned aircraft can fly and in the environmental information and the target position information changes, rapid response, the local change track route, the successful completion of unmanned aircraft reconnaissance and combat tasks of multiple moving targets. The simulation results show that the algorithm can effectively combat the moving target, reduce the search space and shortens the planning time, improve the search efficiency, improve the ability of optimization, is better to solve the problem of multiple mobile target drone attacks algorithm.

2. Establish Voronoi Diagram of Threat Field

Voronoi diagram is on the plane at any given n points p_1、 p_2 、 p_3 、…、 p_n (known as the parent points) connected adjacent to the parent point of the triangle , then do these triangles perpendicular bisectors of each side , so in a triangle around each vertex several perpendicular bisector formed with the vertices of the polygon generator , called the polygon Voronoi polygons.

The diagram consists of several polygons called Voronoi diagram. There are many Voronoi diagram construction algorithm, indirect method (also called dual generation method) using the most common, namely use the duality of Voronoi diagram, the first generation of its dual element Delaunay triangulation .The concept of Voronoi diagram above shows that each Voronoi edge are a threat to the adjacent two points perpendicular bisector.

Voronoi diagram has the main features as following:

(1) Each Voronoi polygon only contains a parent point.

(2) The figure of each edge is adjacent to the vertical bisector of the threat, the Voronoi polygon points at the edge of the distance apart is exactly equal to the length of its side generatrix.

The unmanned aerial vehicle (uav) flight points of the area of can be expressed as radar threat and ground missile threat, threat not can change detection performance information exchange between points.Unmanned aerial vehicle (uav) flight level remains the same, to keep problems to a two-dimensional cooperative path planning problemThe threat to the field of the Voronoi diagram is shown in figure 1:

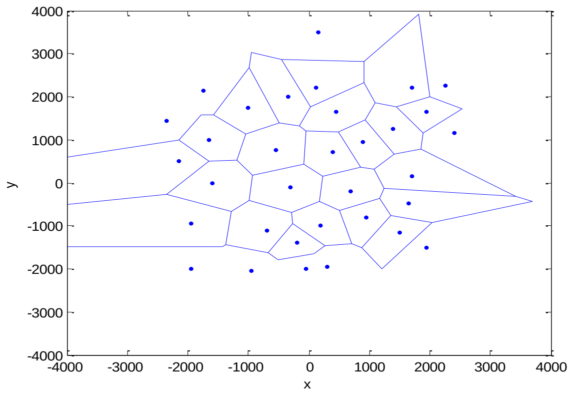

Figure 1. Threat Modeling Voronoi Diagram

In figure 1,the threaten points as a parent, the edge of Voronoi diagram is a threat to midperpendicular, point is at the edge of all threat point farthest point on the plane.If according to the characteristics of the Voronoi diagram of the unmanned aerial vehicle (uav) flight according to the Voronoi polygon edge, is the threat of uav threatened by two adjacent points is the smallest, the optimal safety of unmanned aerial vehicle (uav) at this time.

3. UAV Attacks Multiple mobile Target based on Voronoi Diagram of Dynamic Path Planning Method

3.1 Path Performance Index Analysis

UAV flying along the edge of the Voronoi diagram , you need to define an evaluation function to estimate the cost of each edge , in order to find the optimal path. In this paper consider the cost of two aspects: First, the UAV fuel price , the second is the threat of price.

The first aspect ,it can be assumed that the UAV flying at a constant speed , the geometric path length limitations and associated fuel , can be expressed as $J_{fuel,i} = L_i$, L_i is the length of the i-th edge ..The second aspect , the UAV maintained at a certain height after takeoff into the cruise phase , the main threat in the cruise phase is anti-aircraft fire from the enemy , weather conditions , terrain , etc., we only consider the threat radar and air defense missile.

3.1.1 Radar Threat Price Calculation

Since the intensity of the reflected radar echo radar is inversely proportional to its distance to the fourth power , the threat of price UAV flying along the edge of the Voronoi diagram can be considered a threat at the edge of the radar integration .To simplify the calculation , you can discrete calculations each Voronoi edge, as shown in Figure 2 , take 1/6,1/2 and 5/6 of the distance to each threat to calculate the value of the threat on behalf of each side .For the n-th edge , the cost of the radar threat can be expressed as following:

$$J_{radarThreaten} = L_i \sum_{j=1}^{N} \left(\frac{1}{d^4_{1/6,i,j}} + \frac{1}{d^4_{1/2,i,j}} + \frac{1}{d^4_{5/6,i,j}} \right)$$

(1)

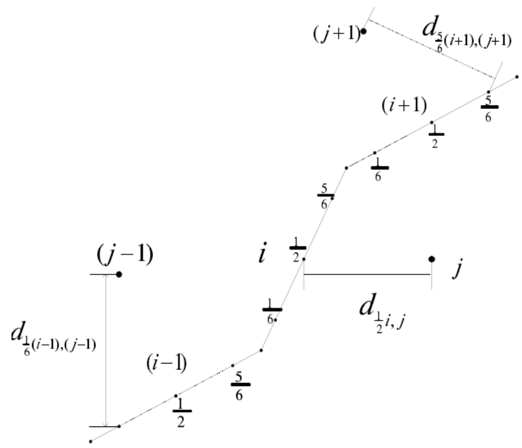

Figure 2. The Calculation Chart of Radar Threat to UAV

Where : N is the number of threat radar field , L_i is the distance between the i -th paragraph of Voronoi diagram ; d is a threat to the distance between the body of the i -th paths .

Note : Each has a strong radar scope , when the UAV fly within this range, with probability one hundred percent will be detected and destroyed . Therefore, we must avoid the radar.

Assuming its scope is a radar of a circle, the radius of r_0 circle , if the Voronoi diagram L_i strip away the first side to radar point is $d_{i,j} \le r_0$, then $J_{radarThreaten} = \infty$.

3.1.2 Surface-to-air Missile（SAM）Threat Price

SAM threat price and radar detection probability, Radar Intercept guidance, information transmission probability of transition probability, missile reliable emission probability, missile flight reliability probability of kill probability of single missile volley, and related to the number .To simplify the calculation , take every edge of 1/6 , 1/2 and 5/6 the distance to each threat to calculate the threat on behalf of little value . For the L_i -th strip , SAM threat price can be expressed as following :

$$J_{missileThreaten} = K \sum_{j=1}^{M} \left(\frac{\Delta h_{1/6,i,j}}{d_{1/6,i,j}} + \frac{\Delta h_{1/2,i,j}}{d_{1/2,i,j}} + \frac{\Delta h_{5/6,i,j}}{d_{5/6,i,j}} \right) \quad (2)$$

Where : K is a coefficient , Δh is SAM sites for UAV relative height , d is the radial distance away from the UAV missile source.

3.1.3 The total cost of threat

In summary, the i-th edges threat price is the consideration of the i-th edge radar threat price and the i-th missile threat .It can be expressed as following:

$$J_{Threaten,i} = J_{radarThreaten,i} + J_{missileThreaten,i} \quad (3)$$

Since the UAV fuel price is $J_{fuel,i}$, considering the cost of the above two aspects , the final cost of UAVs along the i-th edge flight strip of the Voronoi diagram can be expressed as following :

$$J_i = kJ_{threaten,i} + (1-k)J_{fuel,i} \quad (4)$$

Where :k is the weight that preference factor , reflects a compromise between fuel and threats , ranging from 0 to 1 , it is to be able to intuitively and effectively represent a target decision makers of preference , if the threat more seriously, take the k value weight is large, on the contrary , is small. The whole path performance indicators is can be expressed as following:

$$J = \min\left(\sum_{i=1}^{i=n} J_i\right) \quad (5)$$

The optimal path of single UAV is the performance indicators minimum path.

3.2 Trajectory Generation and Optimization

On the basic of Voronoi diagram, original trajectory optimization of UAV can be searched by using shortest path. The path planning is not only applied for one direction of trajectory but it should more multidirectional so that the unoriented shortest path searching algorithm is selected in this paper. Original trajectory optimization is generated through selecting unoriented Dijkstra in the experiments of stand-alone trajectory optimization.

The basic train of thought is starting with v_s and search shortest path outward step by step. In the executing process, labeling is given to every vertex. It shows the weight of shortest path from v_s to that point, which is named labeling p (or perpetual mark , it is that labeling value will not change in the whole calculation process once a point get the label p) ,or showing the weight's upper bound of shortest path from v_s to that point, which is named labeling T (also known as temporary label or tentative label , it is that labeling value can be changed if a point v_j get the label T) The method is to change labeling T in every step, and change one point with labeling T into labeling p.The shortest path from v_s to every point can be gained when get through the step of $n-1$ (n is for the vertices in the graph) The Dijkstra algorithm is shown as following:

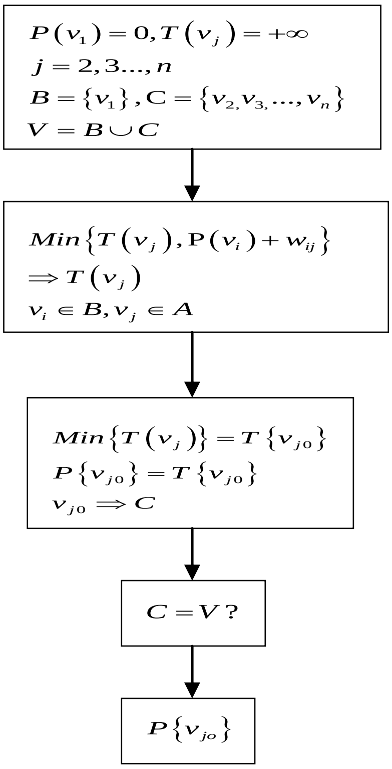

Figure 3. The Dijkstra Algorithm Flow Chart

(1)At the beginning, put labeling p to starting point v_s, $p(v_1)=0$ (also $d(v_{1,v_2})=0$):the others is marked labeling T ,$T(v_j)=+\infty$. s is the collection of points that gained labeling p ,and it is also $s=\{v_1\}$, $\bar{s}=\{v_{2,}.\mathrm{v}_3..v_n\}$

(2)Assuming v_s is the point gained labeling p just, thinking about all labeling v_j adjoin to v_i ,(refer to the arc's midpoint v_j starting with v_i),also $(v_{i,}v_j)\in A$,and v_j 's labeling is T (containing labeling p is not considered).With modification of v_j 's labeling T ,make $T(v_j)=\min\{T(v_j), P(v_j)+(w_{ij})\}$,for all points v_j not adjoin to $v_i : T(v_j)=T(v_j)$.

(3)If there is no labeling T in the point D, the algorithm stops, which has gained the shortest path from starting point to each point. Otherwise, $T(v_{j0})=\min\{T(v_j)\}$. If there are multiple minimum $T(v_j)$, then take any one, putting v_{j0} 's labeling T into label p , then turn to step (1).

It should be pointed out that the starting point and the target point is not in the scope of generatrix in constructing Voronoi diagram. In order to solve this problem, in the starting point and the target point, the artificial potential field method is adopted for planning the local tracks in this paper.

Considering the particularity and limitations of traditional artificial potential field method to solve the trajectory planning of UAV, the artificial potential field function is improved in this paper, its expression follows:

$$U_{att}(p)=\frac{1}{2}\xi\rho_g^2(p, p_{goal}) \tag{6}$$

$$U_{rep}(p)=\begin{cases}\frac{1}{2}\eta(\frac{1}{\rho(p,p_{obs})}-\frac{1}{\rho_o})^2\rho_g{}^n(p,p_{goal}), & \rho(p_{obs},p)\le\rho_o\\ 0, & \rho(p_{obs},p)\le\rho_o\end{cases}$$

(7)

Where: ξ is the gain coefficient of gravity , η is a repulsive force gain coefficient, ρ_o is a threat affect distance, P , p_{goal} , p_{obs} respectively current position ,target position and obstacles of UAV. n is a positive constant, $\rho(p,p_{obs})$ and $\rho_g(p,p_{goal})$ respectively the distance of UAV's current position to obstacles, target. Making the current point to the target point distance $\rho(p,p_{goal})$ into the repulsive force field to make sure repulsive force is relatively smaller and smaller when the search path to point to the target point distance is more and more close. When there has obstacles near goals. It has to ensure the whole potential field function if and only $p=p_{goal}$ and the target point is the global minimum point to avoid the situation of the repulsive force is too large to reach the goal. At this point the repulsive force function expression is:

$$F_{rep1}=\eta(\frac{1}{\rho(p,p_{obs})}-\frac{1}{\rho_o})\frac{\rho^n(p,p_{goal})}{\rho^2(p,p_{obs})} \tag{8}$$

$$F_{rep2}=\frac{n}{2}\eta(\frac{1}{\rho(p,p_{obs})}-\frac{1}{\rho_o})^2\rho^{n-1}(p,p_{goal}) , \tag{9}$$

$$F_{rep}(p)=-\nabla U_{rep}(p)=F_{rep1}n_{OR}+F_{rep2}n_{RG} \tag{10}$$

Where: $n_{OR}=\nabla\rho(p,p_{obs})$ and $n_{RG}=-\nabla\rho(p,p_{goal})$ are the two unit vectors, pointing to the obstacles and the target point from the current point of UAV respectively when the UAV get closer and closer to target distance. The threat source that has shorter distance to target is very weak for the repulsion of field strength of UAV. The repulsion approximate to zero, the drone of the gravitational field is much greater than the effect of repulsive force field at that time. Thus the UAV can fly to target.

4. Simulation

In order to verify correctness and feasibility of the planning method when single UAV attacks multiple moving targets based on Voronoi diagram. Under the environment of Matlab7.0, the simulation experiment was carried out and it was divided the space by step 1 km in the battlefield of 4000 km * 4000 km. Parameter selection for the biggest corner for 60 degrees, the maximum climbing/dive Angle of 45 degrees. The UAV A gets into attack area to attack three maneuvering targets of blue zone. The threat of blue zone has mainly radar threat and low-altitude threat. The movement of the target is discrete, the direction is fixed. The UAV can be able to react in advance according to airborne detection equipment if the target appears moving when the UAV is in the process of tracking. The unmanned aerial vehicles can change track cost weight value according to combat intention of the combat intention when amend trajectory timely, it is to balance the fuel cost trade-off between price and threats.

Firstly the threat of known points, the starting point of planes and three initial target coordinates are given. Building up improved Voronoi diagram at threat as generatrix and calculating the threat of the price terms, and uses the artificial potential field method and the Dijkstra algorithm to find the optimal path of the plane.

In simulation experiments, the initial target is ascertain in advance, so the initial path has been planned out when the UAV flies. The UAV's starting coordinates is (0, 3500), three coordinates of the initial target points are respectively (900140), (1000240), (3000150), the diagram of the UAV hits the first moving target simulation as shown in figure 4:

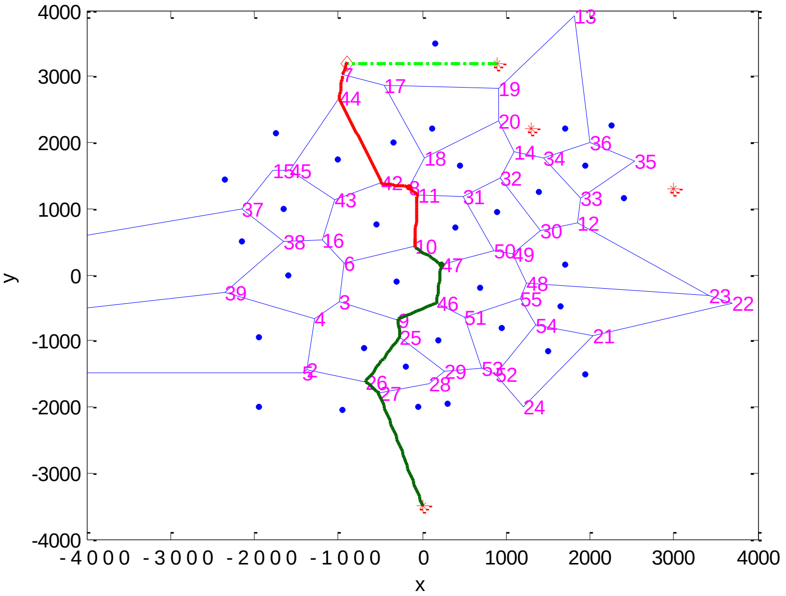

Figure 4 (a) The Simulation Diagram of UAV Attacks the First Moving Target

In figure 4 (a), the starting point of UAV (0-3500) is located in the outside space of Voronoi diagram, so that it can not tracking of the Voronoi diagram. So the artificial potential field method is used in this paper at first and the local path is generated by the starting point to the edge of the Voronoi diagram, and then uses the Dijkstra algorithm to moving target tracking along the side of Voronoi diagram When the UAV flight to position coordinates (0,700), the target is moving, from the point (900,140) to point (-800,320).

After the first strike missions is completed by the UAV successfully. The UAV regards the hit point as the initial point quickly, then reorganizing track from beginning and continue to strike a second task. The UAV regards the second strike as its initial track to go on the third strike missions when the second strike missions is completed The simulation diagram of UAV attacks the second and the third moving target , as shown in figure 4 (b) as well as figure 4 (c)

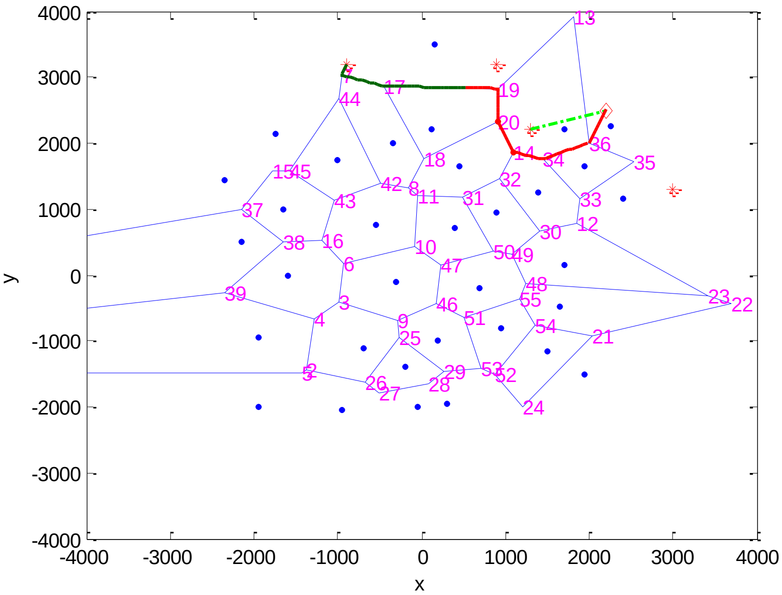

Figure 4. (b) The Simulation Diagram of UAV Attacks the Second Moving Target

In the figure 4(b), the starting point of UAV is (-1000,3300). In the process of the moving target tracking, the target has been moved from point(1100,2200)to point(2100,2700) when the UAV fly to coordinates points(500,2800). But moved target point (2100,2700)is located outside space of Voronoi diagram. It also uses the artificial potential field method as figure 4(a) ,then generate local track from point(2000,2000) to target point.

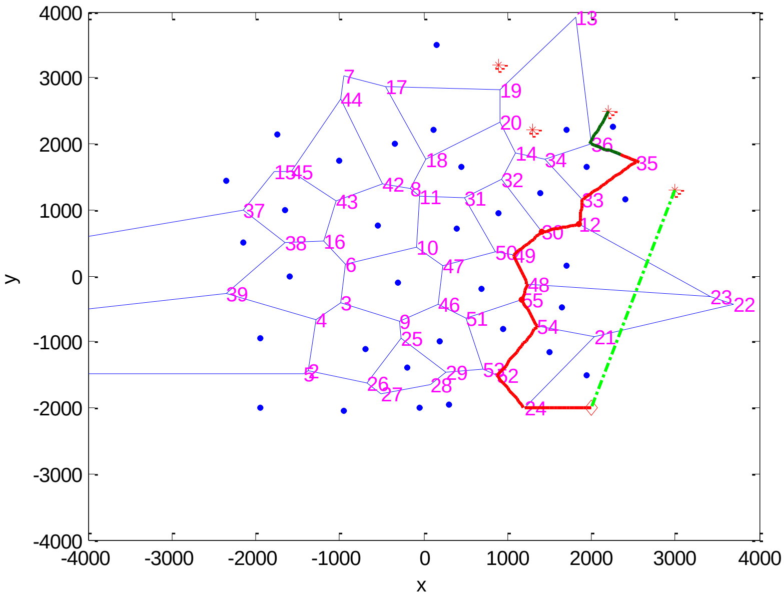

Figure 4. (c) The Simulation Diagram of UAV Attacks the Third Moving Target

In figure 4 (c), the starting point (2100,2700) of the UAV, the moved target point (2000-2000) is located in the outside space of Voronoi diagram, and also uses the artificial potential field method to generated from the starting point of the edge of the Voronoi diagram and the Voronoi diagram to the target of a mobile point of local track, the rest of the track is shown in figure 4 (a) (b), using the Dijkstra algorithm, along the side of Voronoi diagram to moving target tracking.

In figure 4 (a), figure 4(b) and figure 4(c), the green line represents the initial track generated by the unmanned aerial vehicles when the target has not move. And the red line represents regenerate trajectory when target position changes are detected by the unmanned aerial vehicles. The green dotted line is the target's movement track, and the red diamond is the location for target , the overall combat simulation diagram as shown in figure 5:

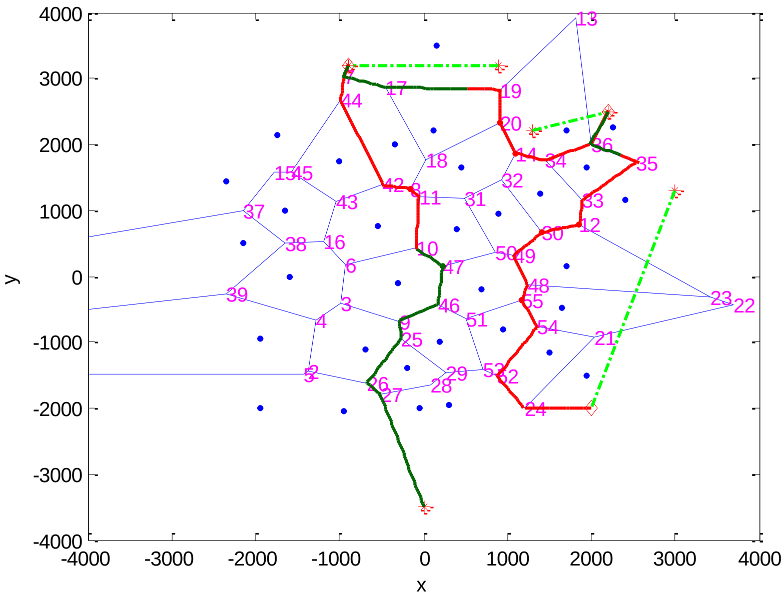

Figure 5. The Total Simulation Diagram of Attacking Multiple Moving Targets

5. Conclusion

Based on the UAV dynamic path planning problem of multiple moving targets, this paper studied it under the dynamic environment. In this paper, the Voronoi diagram based on threat is established according to ground threat type. The trajectory planning is got respectively by the artificial potential field method and Dijkstra algorithm. For the starting point and moved target points of the UAV outside of the Voronoi diagram space, using the artificial potential field method to generated from the starting point to the edge of the Voronoi diagram and local track with moved target points to the Voronoi diagram. For the inside of Voronoi diagram , using the Dijkstra algorithm along the side of Voronoi diagram to moving target tracking. The simulation results show that the combination of two algorithms can not only the best path planning. And it can adjust trajectory timely and attack new target point effectively when the target is moving, which satisfies the requirement of path planning optimization problem. At the same time, reducing the planning time is a try about technological exploration of the UAV tracking effectively and attack the target accurately.

References

[1] M. Degarmo and G. M. Nelson, "Prospective Unmanned Aerial Vehicle Operations in the Future National Airspace System", AIAA 4th Aviation Technology, Integration and Operations(ATIO) Forum, Chicago: AIAA, **(2004)**.
[2] J. Li, X. Sun and M. A. Qiang, "Algorithm and simulation in antiaircraft threats for Unmanned Aerial Vehicles", Journal of System Simulation, vol. 20, no. 16, **(2008)**, pp. 4237-4240.
[3] S. Blackman and R. Popoli, "Design and Analysis of Modern Track-ing Systems", London, Britain: Artech House, **(1999)**.
[4] S. Li, X. Sun and D. Wang, "Real_time route planning algorithm for unmannedaerial vehicles in dynamic environment", Systems Engineering and Electronics, vol. 29, no. 3, **(2007)**, pp. 399-401.
[5] F. Belkhouche and B. Bendjilali, "Reactive Path Planning for 3-D Autonomous Vehicles", IEEE Transactions on Control Systems Technology, vol. 20, no. 1, **(2012)**, pp. 249-256.
[6] L. Singh and J. Fuller, "Trajectory Generation for a UAV in Urban Terrain, using Nonlinear MPC", Proceedings of the American Control Conference, Arlington, **(2001)**.
[7] T. Lapp and L. Singh, "Model predictive control based trajectory optimization for nap-of-the-earth (NOE) flight including obstacle avoidance", Proceedings of American Control Conference. Boston, **(2004)**.
[8] C. Li, C. Zhou and M. Ding, "Research on real-time 3D-route planning of aircraft for dynamic environments", Journal of Astronautics, vol. 24, no. 1, **(2003)**, pp. 38-42.
[9] T. WEI, J. Wang and X. Qu, "Receding optimization method for on-line path planning in dynamic environment", Flight Dynamics, vol. 30, no. 3, **(2012)**, pp. 218-222.
[10] J. W. Lee, B. Walker and K. Cohen, "Path Planning of Unmanned Aerial Vehicles in a Dynamic Environment", Infotech@Aerospace. Louis: AIAA, vol. 3, **(2011)**, pp. 1-17.
[11] J. Ren, X. Gao and Y. Zhang, "Path planning based on model predictive control algorithm under moving threat", Control Theory & Applications, vol. 27, no. 5, **(2010)**, pp. 641-646.
[12] C. Zeng, M. Ding and S. Gusn, "A search algorithm for moving target aircraft track", Journal of aerospace, vol. 24, no. 5, **(2003)**, pp. 444-450.
[13] X. Chen and D. Liu, "An Improved D* algorithm based 3D path planning for UAVs when target is Moving", Lightning and control, vol. 20, no. 7, **(2013)**, pp. 2-5.

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