A FLEET ARITHMETIC ON OVERLAY CAPACITY OF MULTI-AIRCRAFT COOPERATIVE DETECTION BASE ON TRANSFORMED CHAMELEON

D. H. Mao[1*] – Y. W. Fang[1] – X. Zang[2] – X. H.Diao[1]

[1] Department 2, Engineering College of Aeronautics and Astronautics, Air Force Engineering University, Xi'an, 710038, China
[2] PLA Military Representative Office in Shenyang Aircraft Industries (group) Co. LTD, Shenyang, 110034, China

ARTICLE INFO

***Article history*:**
Received
Received in revised form
Accepted

Keywords:
Multi-Fighter Coordinated
Detect Capacity
Cluster and Partition
Fleet-calculate

Abstract:

In allusion to the particularity of Multi-Fighter Cooperative Detection, this paper analyzes the influence of different formation modes of the aircraft.. The framework of basic formation modes is established, moreover, the solutions of these models are also introduced. There is some disadvantage of gridding-method on real-time performance. A transformed chameleon method is used to divide up the big formation and cluster it into the basic ones. The rules-less formations' detect an overlay area and divided into basic ones, can be figured out on the ground of dividing results. In this way, we can reduce the fighter formations to calculate the overlay capacity fleetly. The simulation results indicate that the method meet the real-time needs with error permissibility.

1 Introduction

The classic multi-aircraft cooperative air combat process [1-3] is composed of detecting, tracking and shooting. The process of detecting, as one of the operational chief components, undertakes the task of target spotting and threat discovering. It also provides information about targets and avoiding attacks. That is known as 'eyes' of pilots. In multi-aircraft cooperative air combat, the detection capability of an aircraft carrier in detecting process is different from that in tracking process [4, 5]. In detecting process, the primary mission is to improve detection probability by enlarging the radar-covered area of cooperative fighters. When tracking and distinguishing, keeping as many types of radar as possible is needed to illuminate the target and to improve the precision of target tracking and identification.

According to the completeness of information domain in Network-Centric operating system, studied by Chen Linxin [6, 7], we should confirm the detection area of cooperative aircraft radars after evaluating the completeness of cooperative detection. At present, the researches of radarcooperative detection mainly focus on detecting precision [8-11]. In the area of cooperative detection zones, most studies dwell on qualitative description. Meng Guoming [12] has focused on representation technology of the radar detection range in virtual battlefield environment, which is a reference for simulation.

Chen [7] analyzes the influence of detection range in space with different configurations. For the aircraft formation, the basic formation forms are fixed, although it is a multitudinous formation. Once the detection area range of the basic formation is confirmed, the cooperative detection area can be

* Donghui Mao. Tel.:008618091800946
E-mail address: iheartmay@163.com.

calculated rapidly by cluster analysis. The detection area range is calculated by using geometric methods, when the cooperative fighters are grouped in area. Yang Xiaobin [13] summarizes and analyzes the main cluster methods, besides, he makes a comparison of them, and then gives the ranges. Bai Xue [14] studies measurements and similarities of different objects, classifies them including image clustering, contour grouping and image classification, and gives some useful conclusions. Huang Lei [15] uses the Chameleon algorithm for object clustering in situation of the battlefield, but this method relies too heavily on k in k- nearest neighbor graph.

In this paper: firstly, the basic formation of an aircraft cooperative operation is confirmed and the computational formula for different basic formation detection areas is obtained. Secondly, by introducing both noise distance and angle distance, the chameleon algorithm is improved so as to cover the shortages of high complexity and noise influence when dealing with high dimensional data. Thirdly, the cooperative detection area range is quickly calculated by formation clustering. Finally, an example is given to verify the real-time capability.

2 The Cooperative Detection Area

The capability of cooperative aircraft detection is [16]:

$$P_F = \frac{S_F}{S} = \frac{\bigcup_{k=1}^{K}}{S}, \qquad (1)$$

where, S is the Defense airspace area, S_k means radar scanning area of the fighter k , $S_F = \bigcup_{k=1}^{K}$ is the coverage area of cooperative detection .

$$S_k = \varphi_k R_k^2, \qquad (2)$$

where $\pm\varphi_k$ is the radar azimuth of fighter k , R_k is the radar range.

In any case, the detection coverage area of cooperative aircraft is only based on the formation model, when the radar azimuth and range are fixed. The coverage area in any formation model can be obtained by applying a grid method. But it is fantastic in engineering practice because of the high operations. There is a method to fix this issue. The approximate value is obtained using Geometric way, when the formation model contains few fighters (fewer than 4 fighters). When the formation is huge and the geometric method does not work, we divide them into small ones.

Consider the following small formation model of cooperative aircraft: small formation for dual fighters, horizontal formation for dual fighters, vertical formation for dual fighters, horizontal formation for three fighters, and vertical formation for three fighters. The cooperative detection area is calculated as follows:

Small formation for dual fighters. The two fighters make a small formation with tiny distance of vertical, horizontal and altitude ways, due to the identification characteristics of Doppler radar. The distance capabilities rely on the performances of the both weapon systems. On this occasion, the cooperative detection area is the same as single ones. As shown in Figure 1, the detection areas are overlapping completely.

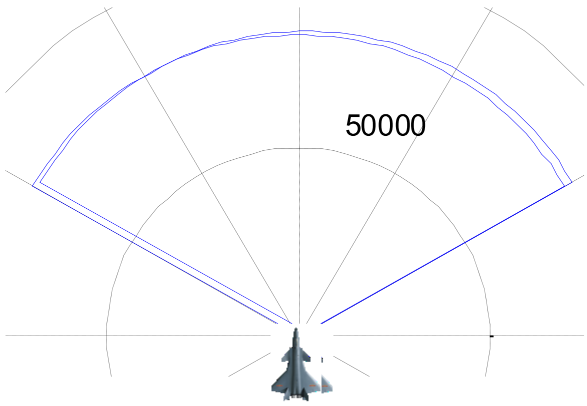

Figure 1. Small formation for dual fighter.

The area can be obtained by Formula（2）.

Horizontal dual fighters. Two fighters in this formation keep a long distance in horizontal in order to enlarge the detection area and promote the precision of position fixing. In that formation the angle of sight between two fighters is limited. The detection area is shown as Figure 2.

In Figure 2, S_M is the overlapping area (which is determined by the radar range, radar azimuth, distance limit and formation models.) . S_O is the blind zone which is determined by radar azimuth and formation.

With geometrical relationship:

$$S_o = LH - \frac{1}{2}L^2\tan\theta + \frac{H^2}{4}\cot\theta - \frac{1}{8}LH\tan\theta\cot\theta + \frac{1}{4}L^2\tan^2\theta\cot\theta, \quad (3)$$

where , L is the vertical distance , H is the horizontal distance.

The area of S_M is approximated to the area of quadrilateral *ABCD*. As a matter of convenience, we move the origin of coordinates to fighter-A. The coordinates of Fighter-B is (x_2, y_2) . $H = |x_2|$, $L = |y_2|$, The coordinates of *A*,*B*,*D* are as follows:

$A \quad (\frac{x_2 - y_2\tan(\varphi)}{2}, \frac{x_2 - y_2\tan(\varphi)}{2\tan(\varphi)}),$

$B\,(x_2 - R\sin(\varphi), y_2 + R\cos(\varphi))$, $D\,(R\sin(\varphi), R\cos(\varphi))$.

The coordinates of C yield

$$\begin{cases} x_c^2 + y_c^2 = R^2 \\ (x_c - x_2)^2 + (x_c - y_2)^2 = R^2 \\ y_c > 0 \\ H > L \\ {x_2}^2 + {y_2}^2 < R^2 \end{cases} \quad (4)$$

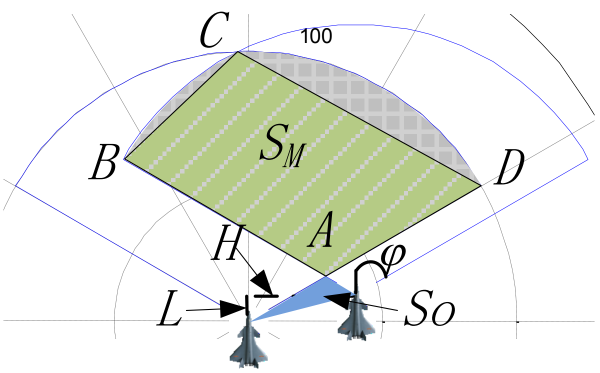

Figure 2. Horizontal formation for dual fighter.

Decompose quadrilateral into triangles ΔADC 、 ΔACB , then the area of quadrilateral can be obtained [17, 18].

Vertical formation for dual fighters. The two fighters keep a large distance in vertical as well as a small one in horizontal. The cooperative detection area is shown as Figure 3.

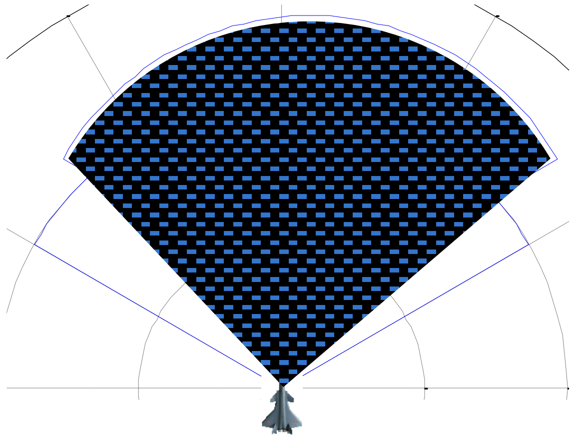

Figure 3. Vertical formation for dual fighters.

For the front fighter, both flankdetection area is enlarged, and the radar range is enhanced for the back one. The area of cooperative detection is equivalent to a sector detection area as the back fighter. As shown in Figure, the formula is as follows:

$$S_T = \phi(R^2 + L^2 - 2RL\cos(\pi - \varphi)) \ , \quad (5)$$

where:

$$\phi = \arccos\frac{L^2 - RL\cos(\pi - \varphi)}{\sqrt{R^2 + L^2 - 2RL\cos(\pi - \varphi)}} . \quad (6)$$

It is the DBC case of the approximate sector.

Vertical formation for three fighters. The rear two fighters make a small dual formation and the front one keeps a large distance in vertical with the rear. It can be analyzed as a vertical dual formation.

Horizontal formation for three fighters. The rear two fighters are at zygomorphic flank of the front one. It is used in cooperative detection, in tracking and attacking. The horizontal and vertical distance between the fighters is limited by data-link, radar range and radar azimuth when a large horizontal distance is kept. As shown in Figure 4, the cooperative detection area is given.

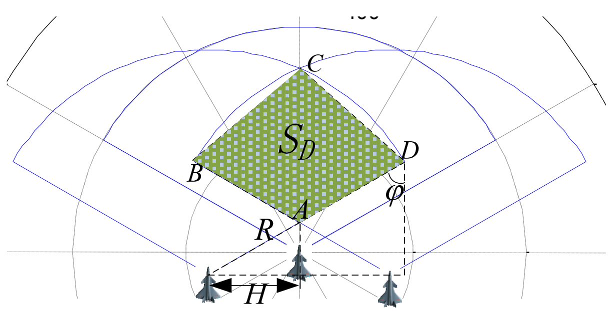

Figure 4. Horizontal formation for three fighters.

The overlapping area follows:

$$S_D = \left(\sqrt{R^2 - H^2} - H\cot\varphi\right)\left(R\sin\varphi - H\right). \quad (7)$$

The partition of any big formation makes a figure of a clustering problem.

3 Chameleon Clustering Arithmetic Operation

3.1 Data Type of Clustering [13, 19]

Review some conception in clustering.

Data-Matrix. Data is a configuration, which has n objects and each object with p attributes, of an object-attribute. Data-Matrix figure $n\times p$ as follows:

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{i1} & x_{i2} & \cdots & x_{ip} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix}.$$

Discrepancy-Matrix, which is an object-object configuration, keeps the discrepancies between any two objects. It figures as matrix:

$$\begin{vmatrix} 0 & & & & \\ d(2,1) & 0 & & & \\ d(3,1) & d(3,2) & 0 & & \\ \vdots & \vdots & \vdots & \ddots & \\ d(n,1) & d(n,2) & d(n,3) & \cdots & 0 \end{vmatrix},$$

where $d(i,j)$ shows the differences between object i and object j, which is generally no-negative. It closes to zero when the 2 objects are closely conformed. Besides, $d(i,j) = d(j,i)$ 。While $i = j$, $d(i,j) = 0$ 。

3.2 Chameleon arithmetic [15] Operation

Chameleon clustering arithmetic is a dynamic model in a hierarchical clustering algorithm. In clustering, if the relative interconnection and relative closeness between classes is relented to inner ones, then combination of these two classes have been applied. The combining process, based on a dynamic model, is helpful to find natural and isomorphic classes. It can be applied to any data type.

Chameleon arithmetic describes objects based on k-nearest neighbor graph, which usually has two stages: the first stage is reached by using a graph partitioning algorithm to mark out relatively independent classes in k- nearest neighbor graph in stage one, and then the second by using a special hierarchical clustering algorithm to repeatedly merge to bring out clustering. It is shown in Figure 5. The node in k-nearest neighbor graph represents the objects. If object A is one of the k most similar objects of object B, there is an edge between A and B. The weight of the edge is represented by similarity. The advantage of this is that the objects are disconnected if the distance between them is far. The edge weight represents spatial density information.

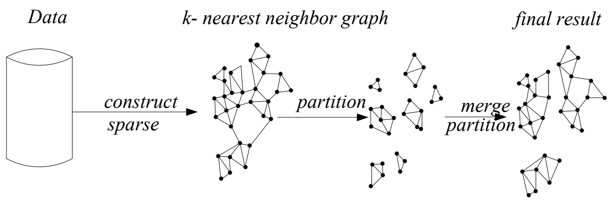

Figure 5. Chameleon arithmetic flow.

The similarity between clusters is determined by the relative interconnection (*RI*) and relative closeness (*RC*). The $RI(C_i, C_j)$ of C_i and C_j are defined as the standardizations of absolute interconnection between them:

$$RI(C_i, C_j) = \frac{2\left|EC(C_i, C_j)\right|}{\left|EC(C_i)\right| + \left|EC(C_j)\right|}, \quad (8)$$

where $EC(C_i, C_j)$ is the edge cut set which divides the C_i and C_j into clusters. $EC(C_i)$ is the edge cut set which partitionsthe C_i correspondence child graph into two parts.

The $RC(C_i, C_j)$ between C_i and C_j is defined as standardizations of absolute closeness between them:

$$RC(C_i, C_j) = \frac{\bar{S}_{EC(C_i, C_j)}}{\frac{|C_i|}{|C_i| + |C_j|}\bar{S}_{EC(C_i)} + \frac{|C_j|}{|C_i| + |C_j|}\bar{S}_{EC(C_j)}}, \quad (9)$$

where $\bar{S}_{EC(C_i,C_j)}$ is the average weight of node C_i and C_j. $\bar{S}_{EC(C_i)}$ is the average weight of edges in C_i. $|C_i|$ represents the number of data points in C_i.

The Chameleon arithmetic steps are depicted as follows:

Step one, generate original clusters.

1) consturct similarity matrix.

2) conceive *k*- nearest neighbor graph based on similarity matrix.

3)generate original clusters with *k*- nearest neighbor graph.

Step two, clusters merge. Use the *RC* and *RI* to determine the similarity. Calculate the RI and RC of every cluster and merge them when RC and RI are greater than T_{RI} and T_{RC}. If there are more than one, clusters meet the limits, and merge into the closest one. Repeat the 2 steps until the last cluster is merged.

4 Transformed Chameleon and Application in Cooperative Detection

4.1 Transformed Chameleon arithmetic Operation

There are some disadvantages about Chameleon arithmetic operations. First, all clusters are to be visited when the original cluster is merged. That makes the arithmetic more complex when it is used in dealing with high-dimensional data sets. Second, in generating the original clusters, all of the partitions are regarded as clusters. That may increase the influence of noise. Therefore, the following improvements are introduced: ①When the original cluster is merging, the noise distance is introduced to the system. The node is a noise if it is out of the range of noise distance, so the node will not be visited in merging step. ②The cluster is merged depending on the angular distance, which is introduced, but not RI and RC. Original clusters are generated by Euclid distance, than they are merged byangular distance to reduce computation complexity.

The angular distance is defined as the acute angle between the flight direction and the connecting line of the two clusters:

$$\cos\lambda_{ij} = \left| \frac{\sum_{k=1}^{3}(x_{ik}-x_{jk})x_{ek}}{\sqrt{\sum_{k=1}^{3}(x_{ik}-x_{jk})^2 \sum_{k=1}^{3} x_{ek}^2}} \right| \quad ,(10)$$

where $\vec{e} = (x_{e1}, x_{e2}, x_{e3})$ is the vector of flight direction. x_{ik} is the *k*($k\leq 3$) dimension of the cluster *i* coordinates. The flight directions of the clusters are the same.

The Euclid distance defined as follows [14]:

$$d(x_i,x_j) = \|x_i - x_j\| = \left(\sum_{k=1}^{3} |x_{ik} - x_{jk}|^2 \right)^{1/2} \quad (11)$$

where *k* is the dimension of the data. It represents the coordinates of the fighters.

In large formation merging, the basic formation has a number of fighters less than three. The transformed arithmetic can be described as follows:

Step one, generate original clusters:

1) Generate the attributes matrix by the coordinates of each fighter.

2) Construct Discrepancy-Matrix $D_0 = (d_{ij})$, and make the weight of each object the same.

3) Give the threshold $\min(R_t, R_d)$, if there is always $d > \min(R_t, R_d)$ for a certain fighter, that the fighter is a noise. Make the two fighters a small formation if $d \ll \min(R_t, R_d)$.

4) Cluster and give it a +1 weight. Single fighters are remaindered.

Step two: clustering.

1) Generate new Discrepancy-Matrix using angle distance.

2) Cluster to vertical formation model with $\lambda_{ij} \leq \lambda_h$, and plus 1 on weight, where λ_h is the threshold for vertical formation.

3) Construct new Discrepancy-Matrix without the clusters which have 3 objects.

4) Cluster to horizontal formation with $\lambda_{ij} \geq \lambda_z$.

4.2 Overlapping Capability of Cooperative Detection

As to large formation model, we firstly construct data-matrix with fighter node. Then partition it to basic ones which contain fighters less than 4. Finally we can obtain the area using 1 as follow:

$$S_F = \sum_{i=1}^{k} S_{Bi} + \sum_{p\in Z} R_p^2 \varphi_p \quad ,(12)$$

where k is the number of basic formations, Z is the noise sets.
The defense area space is the enclosing rectangle. The length and width of the rectangle are the Extreme differences of the detect direction and the vertical one.

$$\begin{cases} L = \max(T_y) - \min(T_y) \\ H = \max(T_x) - \min(T_x) \end{cases} \quad .\ (13)$$

The area is: $S = LH$. The capability is obtained by , (1) .

5 Simulation

Consider that 12 fighters consist of a large formation with the flight direction (0,0,-1). The coordinates of the fighters are as follows:
P1 (0，9，0), P2 (-0.5，9，0.2), P3 (40，9，22), P4 (-35.2，9，13.2), P5 (15，9，26), P6 (94.6，9，79.3), P7 (75，9，60), P8(70，9，81.6), P9 (-30，9，-15), P10 (85.2，9，-3.3), P11 (0，9，20.6), P12 (075.5，9，60.6).
The original position and detection area shows as Figure 6.

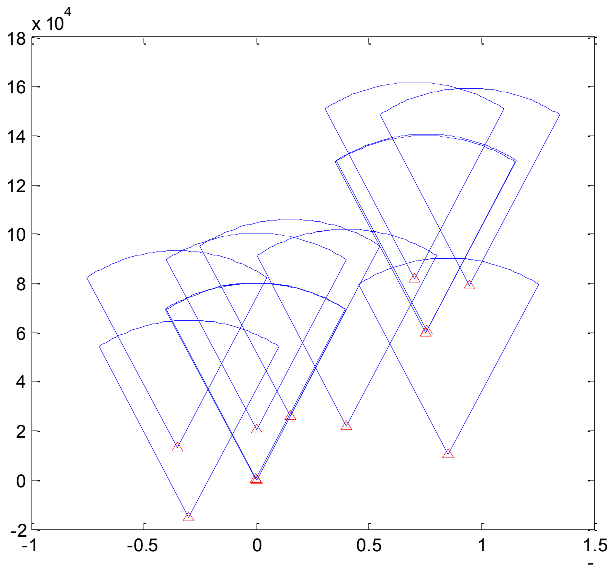

Figure 6. Cooperative detection of formation.

5.1 Partition to basic formations

The cooperative detection area is to be calculated by using transformed Chameleon arithmetic operation.

Step 1. Divide the formation into basic formations, generate original cluster and partition, and record the noises. As shown in Figure 7. represents the small formation and represents the noise. There are 2 small formations and a noise in Figure 7.

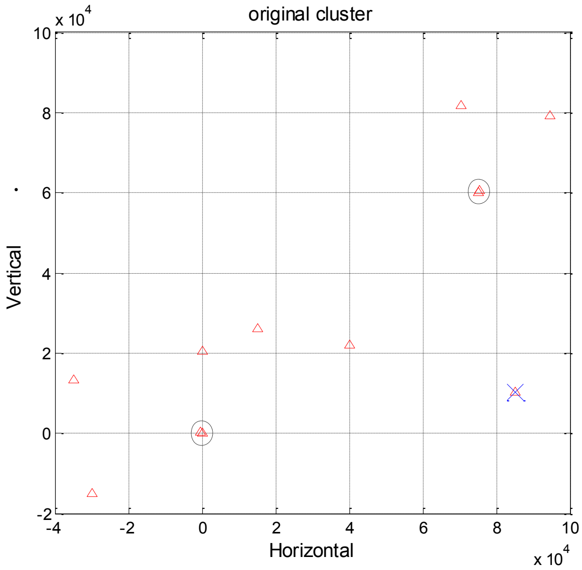

Figure 7. Small formations and noises.

Step 2. Calculate the angular distance, cluster the vertical formation and then the horizontal ones. As shown in Figure 8 and Figure 9, where represents horizontal formation and represents vertical formations.

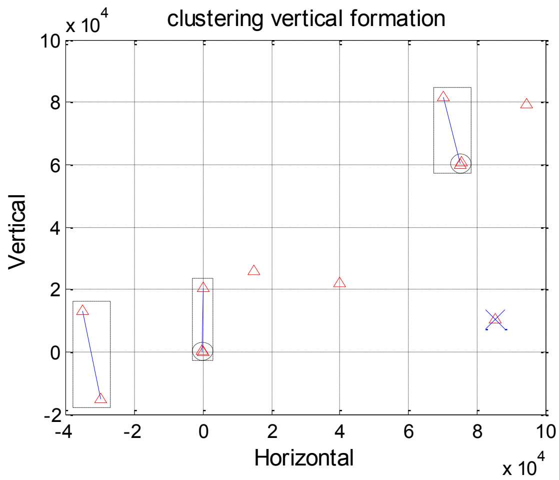

Figure 8. Vertical formations.

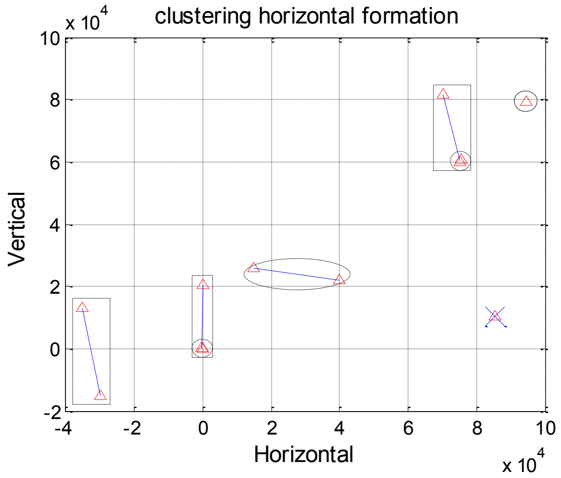

Figure 9. Horizontal formations.

5.2 Detection Capability

The defense area is 37067.6km^2 by applying the assumption in section 4.2.

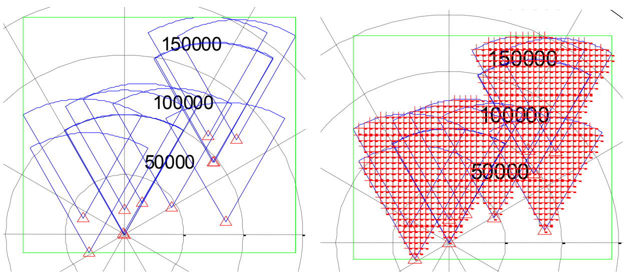

Figure 10. Grid method for detecting an area.

As shown in Figure 10, the area is calculated by applying a grid method. The edge length of the grid is set as 500m to ensure the accuracy, and we can obtain the detection area that is 18463km^2. Using transformed chameleon arithmetic operation, there are 6 basic formations and the detection area range is 19088km^2. About 7% differences exist between them. The comparison is shown in Table 1.

Table 1 Comparison between Grid and TC

	result	Time (second)	
Grid Method	0.4981	4.0158	
Transformed Chameleon	0.5165	Partition:0.0357	0.1988
		Calculate:0.1631	

From the Table we can draw a conclusion that the Time is greatly reduced when using Transformed Chameleon arithmetic operation, which means that the arithmetic can meet the need of real-time capability evaluation on cooperative detection.

6 Conclusion

A computational model for basic formation models of cooperative detection is established by analyzing them. Large formation can be partitioned into basic ones by using a Transformed Chameleon arithmetic operation fleetly. The detection overlapping capability is fast calculated based on the basic formation formulas. That may lay a foundation for evaluating the real-time effectiveness of multi-aircraft cooperative air combat.

References

[1] Xingwei, L., Rongchang, Z., Jinwu, X: *Simulation of effect of air-to-air missile on operational effectiveness of fighter*, Journal of Beijing University of Aeronautics and Astronautics.31 (2005), 9, 963-966.

[2] Yuxian, J., Hui, L., Yang, S.: *Long-range air-to-air missile combat system*, Journal of Beijing University of Aeronautics and Astronautics.31 (2005), 1, 21-25.

[3] Wenhai, W., Siyu, Z., Li, G.: *Improvements of situation assessment for beyond-visual-range air combat based on missile launching envelope analysis*, Systems Engineering and Electronics 33(2011), 12, 2679-2688.

[4] Hang, L., Ming, X., Nanyu, C.: *Task effectiveness evaluation on anti -ship attack of fighter aircraft*, Transactions of Nanjing University of Aeronautics & Astronautics. 29(2012), 2, 164-170.

[5] Yu, X., Yi, Z., Youyi, Z.: *Multiple UCAV Cooperative Jamming Air Combat Decision Making Based on Heuristic Self-adaptive Discrete Differential Evolution Algorithm*, Acta Aeronautica et Astronautica Sinica. 34(2013), 2, 343-351.

[6] Lixin, C., Xingliang, Y., Wanchun, C.: *Analyzing the effectiveness of network centric operating system in information domain*. System Engineering and Electronics. 26(2004), 7,918-924.

[7] Lixin, C.: *Effectiveness Evaluation of Network-Centric Air-Defense Missile System*. Naitonal Defense Industry Press, Beijing, 2007.

[8] Hongjian, G.: *Research on The Models of Aircraft Detection Susceptibility Evluation*

System. Northwestern Polytechnical Univercity, Xi'an, 2002.
[9] Xiao, Y., You, H., Xin, G.: *Application of Multiple Models Algorithm to Cooperative Localization*. Geomatics and Information Science of Wuhan University, 29(2004), 8, 732-736.
[10] Xiao, Y., Zhang, Y., Peng, M.,et,al.: *Two and three-dimensional intrusion object detection under randomized scheduling algorithms in sensor networks*. Computer Networks, 53(2009), 2458-2475.
[11]Xing, C., Zhi-song, B., Wei-ling: W.: *Detection efficiency of cooperative spectrum sensing in cognitive radio network*. The journal of China Universities of Posts and Telecommunications. 15(2008), 3, 1-7.
[12] Guoming, M.: *Research on the Representation of Radar Detection Range in Virtual Battlefield Environment*. National University of Defense Technology, Changsha, 2005.
[13] Yang, X.: *Research of Key Techniques in Cluster Analysis*. Zhejiang University, Hangzhou, 2005.
[14] Xue, B.: *Similarity Measures in Cluster Analysis and Its Applications*, Beijing Jiaotong University, 2012.
[15] Lei, H., Lei, G.: *Method of clustering about situation assessment*, Computer Applications. 26(2006), 5, 1109-1110.
[16] Bing-song, X.: *Research on Key Techniques of Cooperative air combat*, Air Force Engineering University, Xi'an, 2010, 92-93.
[17] Song, C., Xiao-ming, C., Hong-guang, L.: *Advances in New Natural Coordinate Methods for Finite Element Method*, Engineering Mechanics 25(2008), Sup16, 18-31.
[18] Yan, H.: *Study on Overlapping Area Computation Between 2-D Objects For Its Evolutionary Layout*, Xiangtan University, 2011.
[19] Yan, S., Jing-guo, L.: *Clustering algorithm based on two-value property*, Journal of Harbin Engineering University. 25(2004), 4, 499-504.