Function Group Formation Algorithm for Maneuvering Target

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Summary
New function group formation algorithm based on attribute value for space group target was presented, which had the ability to realize function group formation. The uncertainty of measurement space was mapped into the fuzzy attribute value space, and the uncertainty of measurement space was resolved by the fuzzy match mechanism. With lower calculation complexity less than $O(n^2)$, it was more efficient to generate group formation for maneuvering target by simulation results.

Key words:
Maneuvering target, Function group formation, Situation assessment, Clustering procedure

1. Introduction

Dealing with tracing data of multiple targets in real-time has been a key section of comprehensive antiaircraft-prediction intelligence management. According to its attributes (such as position, ID and situation), group formation for maneuvering targets is generated automatically in real-time for describing the battlefield situation. Essentially the group formation for maneuvering target are special clustering procedures for dynamic targets, which will help command system make sure the relations among battlefield situation elements, lessen the disposal of battlefield situation data, and which will be also one of the available information resources to identify the hostile comprehensive plan for further situation analysis. Situation assessment technology is a front topic of information fusion field. As an important part, group formation for maneuvering target has been focused [1-7].

Researchers have made a lot of work about basic elements and methods of target group formation [2-7], especially Johan defined the relation types as couple, attack etc, and took them as the basic of situation discrimination [4]. Johnson defined the relation of maneuvering target as multi-kinematics connection that included lead, package, engagement etc [5]. In realization of algorithm, Everitt discussed a method of alternating targets group formation during data connection [6]. Because the precondition of its realization was under uncertain target attributes, many group formation hypotheses would be produced at the same time and then managed and excluded. Carl discussed a method of realizing the targets group formation after fusion of position and attribute [7]. He introduced a group formation algorithm based on K-mean clustering method and considered the algorithm had gained better effects of group formation on disposal of situation data.

According to definition of having gained hostile space group target situation and attribute based on first-level fusion, we directly calculated the membership degree of attack relation to generate function group formation. The precondition of this algorithm was as same as Carl's [7]. According to our situation assessment, target attributes of measurement space were mapped to the similarity space. The algorithm realized function group formation for traced targets based on their related behavior elements. This algorithm provided a feasible way for inspecting the function group formation of space targets and the situation assessment of battlefield events.

2. Level of Situation Assessment

According to the definition of JDL, data fusion has three levels. The first-level fusion is the assessment of targets position and attribute including target tracing, ID identification and etc. The second-level fusion is situation assessment and the third-level fusion is threat assessment, which focus on assessing battlefield situation based on the first-level fusion, then make sure the models of hostile action and presume their intentions to measure threaten degree of our target.

Target group formation is an important part of the second-level fusion (situation assessment). It pre-disposes the situation data based on the target ID and dynamic attribute to produce one of the useful information resources of situation analysis, and then identifies the hostile comprehensive action plan and battle intention according to the information analysis of geography, time, space, army forces, collaboration relation and hostile battle order. In antiaircraft-prediction this paper defined three levels group formation based on the hostile maneuvering airspace targets observed (see Fig. 1):

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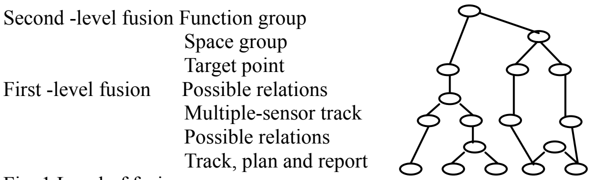


Fig. 1 Level of fusion

(i) Target point. It's a minimum unit platform by which detectors of observational space can distinguish its air routes and obtain its attribute parameters. For example, it can be a flight formation for long-distance space or a plane or a missile for medium-distance or short-distance space.

(ii) Space group. It includes multiple target groups, which have similar attributes and are close to each other. For example, it can be a formation [8].

(iii) Function group. It's a space group, which acts with similar function, or similar intention (as attack or defense).

3. Formal Definition and Description

According to above definitions, based on the situation assessment and attribute assessment of maneuvering target obtained from the first-level fusion, the space groups of observational airspace can be obtained by clustering target points with close and similar attribute action. Function group is composed of some space group meeting certain conditions. To realize function group, first of all, we should extract and analyze the characteristic parameters of space group to measure action characteristic. During an observational-time the situation attribute of target point is in time series. Because situation attributes of space group are gained by calculating situation attributes of target point in corresponding moment, they are in time series too. Target point is defined as:

Definition 1. Target point, a, is an n-tuple containing l length track and multiple target attributes. Let τ be scan period time and $T=l\tau$ be fusion period, the attribute sets of a is equal to { id, $Attr$, $Threat$, $Other$,$(x, y, z, v_x, v_y, v_z,\Psi_s,\beta,\gamma_s)_{0\tau}$,... $(x, y, z, v_x, v_y, v_z,\Psi_s,\beta,\gamma_s)_{i\tau}$,...$(x, y, z, v_x, v_y, v_z,\Psi_s,\beta,\gamma_s)_{l\tau}$ }.

Where id represents the number of target point and $Attr$ represents the attribute of hostile-side and friend-side ("0" represents red-side, "1" represents blue-side, "2" represents neutral-side). *Threat* presents comprehensive threat information ("0" represents no attack ability to red-side, "1" represents having the attack ability) and *Other* represents the other information, such as information of plane type and model, acceleration data, radiant source information, departure airfield data, weapon type data and so on. $(x, y , z, v_x , v_y , v_z,\Psi_s,\beta,\gamma_s)_{i\tau}$ represents the basic state data of target point a in $i\tau$ sampling period. x, y ,z are position of an aircraft in ground reference frame, y is flying altitude. Ψ_s,β,γ_s are yaw angle, tilt angle and roll angle.

Definition 2. Space group. Let S be observational airspace of red-side in time $[t_p, t_q]$ and Y is target point set in S. if $\exists\gamma\in Y$, and $\forall\gamma_i\in\gamma$, in recent l sampling-periods and spatial attribute set Ω of target points, the similarity between $\exists\gamma_j\in\gamma$ and γ_i is $sim_\Omega(\gamma_i, \gamma_j)\geq h$, where h is a given threshold. Then γ is called a space group under h.

To gain the similarity of target point in attribute set Ω for space group formation, we can define position similarity of airspace target points, identity similarity and velocity vector similarity. Any space group γ can be regarded as an n-tuple containing l-length track data and multiple attributes. The track data can be gained by calculating the barycenter track data of all target points in space group γ. Let τ be scan period and $T=l\tau$ be fusion period, the attribute sets of γ is equal to { id, $Attr$, $Threat, Other$,$(x, y, z)_{0\tau}$, ...$(x, y, z)_{i\tau}$,...$(x, y, z)_{l\tau}$, }. Where id represents the number of target point and $Attr$ represents the attribute of hostile-side and friend-side. *Threat* presents comprehensive threat information and *other* represents the other information.

Definition 3. Attack relation. Let $O=\{o_1, o_2, ..., o_k, ...o_m\}$ be the present ground guarded target set of red-side, $X=\{x_1, x_2, ...x_i, ..., x_n\}$ be a certain space group set of blue-side and $\forall x_i\in X$, $Attr(x_i)=1$, $Threat(x_i)=1$, then a fuzzy relation R (2-tuples) from X to O is a fuzzy set from X to O, which is called attack relation. Its membership degree function is represented by $p_R(x, y)$: $p_R X\times O\rightarrow[0,1]$.

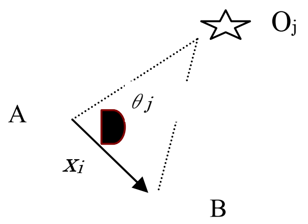
From the point of target attribute and dynamic attribute [3-4], the membership degree of attack relation between blue-side attack space group x_i and certain red-side ground guarded target o_j is mainly determined by:

(i) Space distance. The closer the blue-side space group x_i flies to the red-side target o_j , more possible will x_i attack o_j. When their distance is shorter than the available attack range of ε, $\mu_R(x_i, o_j)=1$.

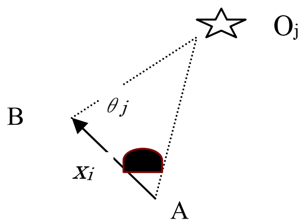
(ii) Flying direction. Out of the available attack range of blue-side space group x_i attacking o_j, the bigger the gradient of x_i flying to red-side target o_j, more possible will x_i attack o_j. . x_i is regarded as close to o_j unless the x_i track projection closes to o_j by inclination angle of x_i to o_j less than θ (for example,$\pi/2$) , or $\mu_R(x_i, o_j)=0$.

The following definition is for the membership degree calculating of attacking relation.

Definition 4. Direction characteristic value. Let $bdre(x_i)$ be the characteristic value of space group x_i and its data is generated from $bdre(x_i)=\cos(\theta_j)$, where θ_j is inclination angel of flying direction of space group x_i to target o_j ($0\leq\theta_j\leq180$).



(a) θ_j far from target o_j



(b)θ_i close to target o_i

Fig. 2. The calculation of direction characteristic value of space

In Fig. 2, there are two cases of space group x_i moving from point A to point B. Obviously θ_j is bigger when it is far from target. As the length of three sides AO_j, AB and BO_j can be calculated, the cosine value of angle BAO_j can also be calculated according to the law of cosines. That is direction characteristic value of space group x_i. The direction characteristic value increases monotonously with the gradient of a space group flying to a target.

Sensor scan period τ is a small interval and $l\tau$ is the interval between the first group formation and the second group formation (group formation period). l is a small integer. As during a fusion period the dynamic characters (such as speed, position, direction) of target change continuously, the dynamic characters of l scan periods for same target are defined as their average to minimize mistake observed and keep robustness of calculation. During l periods, the direction characteristic value is considered as $bdre(x_i) = cos(\sum_{i=1}^{l}\theta_j / l)$.

Definition 5. Distance function factor. The distance function factor between space group x_i and target point θ_j is expressed as $bdis(x_i, o_j)$. According to experience, $bdis(x_i, o_j)$ is the fuzzy relations of fall half normal distribution.

$$bdis(x_i, o_j) = \begin{cases} 1 \quad , & 0 \le d(x_i, o_j) \le \varepsilon \\ e^{-k_1(d(a,b)-\varepsilon)^2}, & d(x_i, o_j) > \varepsilon, k_1 > 0 \end{cases}$$

ε is the threshold for distance discrepancy between blue-side space group and red-side target (Definition 3). $d(x_i, o_j)$ as space distance between x_i and o_j. In l cycles,

$$bdis(x_i, o_j) = \sum_{i=1}^{l} bdis(x_i, o_j) / l \, .$$

According to **Definition 4** and **Definition 5**, the membership degree of attack relation can be confirmed. We take x_i approaching m targets $o_1, o_2, \ldots o_k, \ldots o_m$ with angle $\theta_1, \theta_2, \ldots\theta_k, \ldots\theta_m$ respectively and if the space distance between x_i and o_j is $d(x_i, o_j)$, at a moment the membership degree of attack relation can be expressed as follow:

$$p(x_i, o_j) = \begin{cases} 1 \ , & d(x_i, o_j) \le \varepsilon \\ bdis(x_i, o_j) \bullet bdre(x_i), & d(x_i, o_j) > \varepsilon \ \ and \ \ arccos(bdre(x_i)) \le \hat{\theta} \\ 0, & d(x_i, o_j) > \varepsilon \ \ and \ \ arccos(bdre(x_i)) > \hat{\theta} \end{cases}$$

P is a $n \times m$ matrix which indicates the membership degree of attack relation between n blue-side space groups and m red-side targets. P_{ij} is the membership degree of attack relation between the i th blue space group and j th red target. The column of matrix is blue-side space group list and its row is attack target list.

Definition 6. Function group. The blue-side space group set attacking same red-side target. Two kind of function group are defined as follow:

(i) Take S as red-side scout airspace in time $[t_p, t_q]$, X as space group set in S, and O as red-side target set. X is a cooperation function group under threshold g if $\forall x_i \in X, \exists o_j \in O$ such that x_i for membership degree of o_j attack relation, $P_{ij} \ge g$.

(ii) The blue space group that has no attack relation with any red-side target is called as independent function group. The blue-side independent function group that is inspected by red-side at antiaircraft-prediction stage may be space group without direct threat for red-side target or without the task to attack local target.

Obviously, if taking x_i as space group and $o_1, o_2, \ldots, o_j, \ldots o_n$ as red-side target set, the necessary and sufficient condition for blue x_i to become an independent function group is that the membership degree of attack relation matrix p is with p_{ij}□g.(j=1..n).

4. Function Group Formation Algorithm

Based on above definition, function group formation algorithm is:

Supposing S is the observable airspace for current sensor and XT is space group set. The generation of function group in airspace S is same as procedure as having got the intensity of attack intention from hostile-side groups for targets and making analysis based on gained result. The detail steps of the algorithm are:

Step1.Identify the results of identity from first-level fusion, and delete the elements (*Attr*=0) in neutral-side space group from space group set *XT* and non-blue fight space group (*Threat* =0). Get the all attack space group set *X* from current airspace of blue-side and hostile-side attack target set O (including red-side fixed ground target and space group of airspace).

Step2. Get the estimated position of current airspace target point and calculate the direction character value $bdis(x_i, \theta_j)$ of each space group in X for current target set O={ $o_1, o_2, \ldots, o_j, \ldots o_n$}

Step3. Calculate the all distance function factors $bdis(x_i, o_j)$ of each space group in X for current target set O={ $o_1, o_2, \ldots, o_j, \ldots o_n$}.

Step4. Get matrix *P* as membership degree of attack relation between blue-side space groups and red-side targets.

Step5. Transform *P* into *BOOL* matrix *Q*. and take *g*. Q_{ij} =0 as threshold *iff* $P_{ij} < g$; Q_{ij} =1 iff $P_{ij} \geq g$.

Step6. Generate cooperation function group by column vertex of matrix Q and independent function group by row vertex of matrix Q.

Fetch column vertex $Q_j = \{Q_{1j}, Q_{2j}, \ldots Q_{ij}, \ldots, Q_{nj}\}^T$ from *BOOL* matrix *Q* while *j* from *1* to *m* and the element whose value is *1* from Q_j to create cooperation function group, and fetch row vertex $Q_i = \{Q_{i1}, Q_{i2}, \ldots Q_{ij}, \ldots, Q_{im}\}$ from *BOOL* matrix *Q*. If Q_i=0, the corresponding space group is an independent function group.

Step 1 to 3 is to deal with the n space groups' position and status attribute value and get the character attribute value of *n* space groups for *m* targets. For the data in *l* periods, the time complexity in step 1, 2, 3 will not exceed $O(n \times m \times l)$.*l* is a small positive integer constant, generally $m << n$. So, $m \times l < n$ and time complexity $O(n \times m \times l) < O(n^2)$. The time complexity in step 4,5,6,7 is $O(n \times m)$, also less than $O(n^2)$.

In conclusion, the time complexity of function group formation algorithm is $O(n \times m) < T(n) < O(n^2)$.

5. Simulation Experiment

To evaluate the algorithm proposed in this paper, we created three different scenarios that were designed for situation elements. In the simulation, blue multi-maneuvering targets attacked the red multi-defended targets.

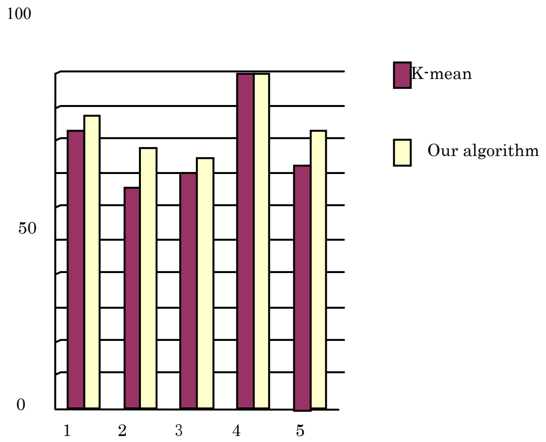
The situation change simulated in the scenario was to set in a fusion cycle of the function group change. Space group was considered as basic granularity of element cluster. Function group formation algorithm was used to calculate the situation change in a fusion cycle between t=0 τ and t=4 τ . This helped us judge whether the original function groups had turned into new ones by group and group formation.

We clustered both the way of seventeen scenarios in three scenario sets based on K-mean clustering algorithm [7] and the way of function maneuvering algorithm based on similarity proposed in this paper. We compared their performance. The experiment was carried out on PIII-933. The simulation program was developed with VC.net to demonstrate obviously group formation procedure and result. We developed a 3D engine based on OPENGL. For designing scenario easily we specially designed scenario-editor in 3D engine.

The movement tracks of targets in each scenario were generated from the following flight control equations [9]:

$$\begin{cases} \frac{dv}{dt} = g(n_x - \sin\theta) \\ \frac{d\theta}{dt} = (g/v)(n_y \cos\gamma_s - \cos\theta)) \\ \frac{d\varphi_s}{dt} = -(g/v)(n_y \sin\gamma_s / \cos\theta \end{cases}$$

$$\begin{cases} \frac{dX_d}{dt} = v\cos\theta\cos\varphi_s \\ \frac{dY_d}{dt} = v\sin\theta \\ \frac{dZ_d}{dt} = -v\cos\theta\sin\varphi_s \end{cases}$$



1= invariable group; 2=variable group; 3= independent group; 4=neutral group; 5= colligation group

Fig.3. Precision comparison

Where $\varphi_s, \theta, \gamma_s$ respectively denote the yaw angle, tilt angle and roll angle of an aircraft track. X_d, Y_d, Z_d are projective position of the target in three axis of reference frame. *g* is the gravity acceleration, *V* is the velocity vector and *t* is current time. η_x, η_y are respectively the tangential overload and the vertical overload. In the simulation of aircraft maneuvering flight, η_x, η_y and γ_s act as movement controlling parameter. Maneuvering actions such as smooth fly, left and right round even pull and large round can be generated in time by setting different controlling parameter value. The initial state for each target is nonmaneuvering fly.

Firstly, we compared the accuracy of the two algorithms. Because the change result of function group and attack intent of maneuvering target had been confined in each scenario, the accuracy was got by comparing anticipant result with the two algorithm results. We calculated: (1) accuracy judge for invariable intent group (by space group granule); (2) accuracy judge for variable intent group (by space group granule); (3) accuracy judge for independent function group; (4) accuracy judge for neutral group; (5) accuracy judge for colligation. The results of comparison were as Fig.3. Because detecting measure of fuzzy similarity is suitable to objective situation and overlap between classes is allowed, the situation that one space group belongs to different function groups can be judged. So average clustering accuracy is higher.

For farther comparing algorithms with efficiency, we tested the time for function group formation created by the two maneuvering algorithms on scenario set *S1* including 3 scenarios, scenario set *S2* including 6 scenarios and scenario set *S3* including 8 scenarios. We finally calculated average group formation time each scenario. The results listed in Fig.4 indicate that algorithm in this paper has less mean time increase and smoother growing trend. The reason is that our algorithm reduces the dimensions of character vector by directly calculating membership degree of attack relation, while K-mean algorithm takes multi-character attribute value into account as clustering character vector respectively [7].

In conclusion, the algorithm presented in this paper is better than K-mean target group algorithm.

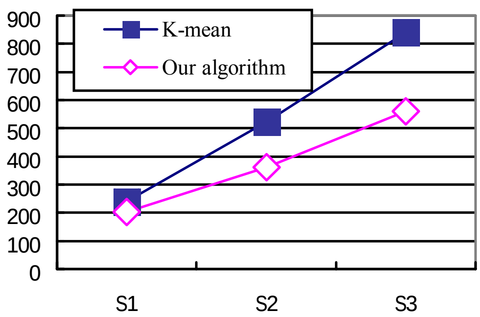


Fig.4.Efficiency comparison (average time of group formation)

6. Conclusions

By the study in this paper, the following conclusions are made:

(i) Our algorithm can process the time series of maneuvering target action with attribute variation and realize function group formation dynamically. This provides a feasible way for maneuvering target group formation.

(ii) The time complexity of our algorithm is less than $O(n^2)$. The simulation experiment shows that this algorithm has higher accuracy and efficiency of group formation than K-mean target group formation algorithm.

(iii) It is very important to choose a certain threshold to apply in calculation of attribute similarity. So it must be decided according to real condition and given by domain expert.

References

[1] Endsley, M. R. & Garland, D. J. (Eds.), Situation Assessment Analysis and Measurement, Mahwah, New Jersey: Lawrence Erlbaum Associates, Inc., (2000)

[2] Junwen G., Zheng Q., Shengping H.，Hexiao H., Simulation of Space Group Formation for Maneuvering Target, Journal of Xi'an Jiaotong University,(2006),40(12):1378~1382(in Chinese)

[3] Edward J. W., Use of domain knowledge models to recognize cooperative force activities, in Proceedings of the 2001 MSS National Symposium on Sensor and Data Fusion, San Diego, CA, (2001)

[4] Johan I., Situation assessment in a stochastic environment using Bayesian networks [Dissertation], Linköping University, (2002)

[5] Johnson, W. T. & Dall, I.W., From kinematics to symbolic for situation and threat assessment, in Proceedings of Information, Decision and Control, (1999) 497~ 502

[6] Everitt, R.G. & Marrs A.D., Hypothesis management in situation assessment, in Proceedings of IEEE Aerospace Conference, (2003), 4 (4): 1895~1903.

[7] Carl G. Looney & Lily R. Liang, Cognitive situation and threat assessments of ground battle spaces, Information fusion, (2003), 4: 297-308.

[8] T.John Koo & Shahram M.S, Formation of a group unmanned aerial vehicles (UAVs), in Proceeding of the American Control Conference. Arlington, (2001)

[9] Q.S Chen (ed.), A manual for Airplane flight performance computing(in Chinese), Flight Dynamics Magazine Agency, Beijing, (1987)

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