A clustering algorithm based on FR-ENN for situation awareness

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Abstract—Targets need to comply with the special formation rules when executing battle tasks. This paper presents an algorithm based on Formational Recognition and Extended Nearest Neighbor (FR-ENN) theory to perform the target clustering for situation assessment. The core idea of the proposed algorithm is to group the relative targets by changing the limit value intelligently and recognize the battle formation with the triangular character recognition in order to help commander apperceive the situation better. The experimental results based on five scenarios show the effective of the proposed method.

Keywords—Situation Assessment, target clustering, formational recognition, extend nearest neighbor

I. INTRODUCTION

Situation Awareness (SA) is critical because it frequently guides decision making and action [1]. During the last twenty years the concept of situation Awareness (SA) has become more and more important. The most widely accepted definition about SA is Endsley’s human-centric interpretation [2] that “situation assessment is the perception of elements in the environment within a volume of time and space (level 1), the comprehension of their meaning (level 2), and the projection of their status in the near future (level 3)”. However, such assessment in complex situations may be difficult to achieve. Surveillance systems are commonly complex in function and structure because they process and present huge quantities of heterogeneous data from multiple sources (radars, cameras, automatic identification systems, etc.). Monitoring this kind of systems is a challenging activity for humans, due to not only the amount of information, the high number of variables involved or the opacity and complexity of the data mining techniques used in the detection process, but also other factors, like time pressure, high stress, inconsistencies and the imperfect and uncertain nature of the information.

From the formal definition of SA [7], situation awareness involves perceiving critical factors in the environment (Level 1), understanding what those factors mean (Level 2), and understanding what will happen in the situation in the near future (Level 3; see Figure 1). Additionally, SA is affected by environmental, physical, emotional, and other cognitive factors, known as SA Demons, that may affect the individual’s ability to make decisions.

II. CHARACTERISTIC IN TARGET CLUSTERING

There are some distinguishing features about target clustering in the real war situation. First, the observed scale of group is depended on the level of the operational commanders. A consuetude in command and control is that commander will follow the groups which are two levels lower than his at most. Commanders who myopically focus on tactical details may miss higher-level context or implications of force actions. Consequently, filtering and providing useful group information for commander considering is necessary. Second, targets are gathered through spacial algorithm, and task relations continuously. Every level cluster means different to the operational commanders, so demonstrating trust and developing a trust-based organization is critical in target clustering.
clustering. Finally, the amount of entities in a small combat is limited and they always comply with the special formation rules when executing tasks. It means that Formation is a special character that can guide commanders to comprehend the relations among targets and decide early what they are going. As an important property of target clustering combat formation reflects the cooperative relationships among group members when performing the battle tasks. It is an observable arrangement of vehicles in a group that can suggest or confirm something about the identity and near-term purpose of the group entity. Air and navy force units sometimes move together in formations in order to travel efficiently and securely in groups, or to gain tactical advantage by coordinated maneuvering. In order to provide much more significant battlefield information and support commanders make decisions much better, it is necessary to research the formation recognition problem based on situation assessment.

Some typical battle formations are presented here to instruction the arrangement of vehicles in a group. The current phase of research is focused on the recognition of the following battalion-sized groupings. Fig. 2 is examples illustrating the line abreast and wedge for a two ship formation.

**Line Abreast:** Principal attribute is a linear trace composed of the majority of the battalion's combat vehicles in line abreast. Its shape may be a shallow curve, or a combination of curved, wavy or fairly straight segments. One or more columnar tail groups may trail behind.

**Wedge:** Principal attribute is a (deformable) V-shaped forward line of vehicles. It faces the direction of travel, similar to formations of migrating birds. One or more columnar tail groups may appear within or behind the open, trailing side of the V.

**Column:** Vehicles driving in line ahead, with each vehicle attempting to follow the path of the one in front of it, often conforming to the lead vehicle’s tread marks. Characteristic shape is a line which may be straight, curved, or kinked.

III. FORMATION RECOGNITION

Most approaches to formation pattern recognition are based on templates. Schwartz [13] describes the use of templates for recognizing formations of moving objects on a frame-by-frame basis. Our approach examines the shape which is the orientation of the linear arrangements within the group with the special triangular character recognition.

![Figure 2. Some typical formation](image1)

Two targets are always considered as a team when executing the battle tasks. So the formation of two-ship model as Fig.3 is an important part to be studied. Fig.4 illustrates how our method to deal with the more targets situation. The location information should be projection transformed on the same horizontal plane during the pre-processing. Then we can draw broken line to form a triangle along horizontal and vertical direction. $x_i, x_j, x_q$ mean the targets or the point of intersection. $d$ and $\theta$ have been described parameters to describe the special triangle. $d$ means the distance between two targets. $\theta$ means the angle between vector $x_q-x_i$ and the horizontal line or between vector $x_q-x_i$ and $x_q-x_j$. $\cos \theta = 1$

When two target perform fairly straight in a line on the horizontal or vertical direction. If the number of elements in a battle group is more than three, our approach will choose three targets which are leftmost, rightmost and the front of the group in order to form the triangle we will measure (Fig.4)

$$d = \left\| x_i - x_j \right\|$$  \hspace{1cm} (1)

$$\theta = \frac{180}{\pi} \arccos \frac{(x_q - x_i)^T (x_q - x_j)}{\left\| x_q - x_i \right\| \left\| x_q - x_j \right\|}$$  \hspace{1cm} (2)

$$\varphi = \frac{180}{\pi} \arccos \frac{(x_q - x_i)^T (x_q - x_j)}{\left\| x_q - x_i \right\| \left\| x_q - x_j \right\|}$$  \hspace{1cm} (3)

Where, $d$ means the longest distance among the lines our method built, $\theta, \varphi$ reflect angles of the horizontal and vertical direction. After calculating the value of each parameter, we should make a scene whether the formation is change using the following formulas.

$$d' = \begin{cases} 
1 & \text{if } \frac{d_{T2} - d_{T1}}{d_{T1}} \leq \text{Limit1} \\
0 & \text{others}
\end{cases} \hspace{1cm} (4)$$

$$\theta' = \begin{cases} 
1 & \text{if } \frac{\theta_{T2} - \theta_{T1}}{\theta_{T1}} \leq \text{Limit2} \\
0 & \text{others}
\end{cases} \hspace{1cm} (5)$$
\[ \varphi' = \begin{cases} 1 & \text{if} \quad \frac{\varphi_{T3} - \varphi_{T1}}{\varphi_{T1}} \leq \text{Limit 3} \\ 0 & \text{others} \end{cases} \quad (6) \]

Note that \( T1 \) and \( T2 \) is the time frame next to \( \text{Limit 1, Limit 2, Limit 3} \) are parameters to measure the range of group. If \( d' \sim \theta' \sim \varphi' = 1 \), it can infer the conclusion that formation has changed.

IV. FR-ENN ALGORITHM

A variety of traditional techniques exist for target clustering. They can be divided into two classes. When the number of clusters is explicit, algorithms such as K-means[17], FCM which involve choosing initial clusters, assigning each sample to the nearest cluster, updating the parameters of the clusters, and continuing until the process converges can be used. When the number of clusters is not known, hierarchical procedures (top-down splitting or bottom-up merging) and NN (nearest neighbor algorithm) are useful.

A. EXTEND NEAREST NEIGHBOR APPROACH

The nearest neighbor (NN) rule is a non-parametric clustering method which is simple, yet effective. It is better suited to data where compact and persistent groups of objects tend to form elongated clusters in space-time. However, NN also has its own drawbacks which is its sensitivity to noise that can cause the algorithm to generate spurious links between clusters. This section presents a technique based on extended nearest neighbor (ENN) approach for grouping moving targets as a cluster.

Traditional NN algorithm starts with one sample in the space, computes the distances between all targets, links the two nearest targets as a group, and repeats until a single target remains. When the distance metric between targets is the maximum distance between the members of the targets, the algorithm encourages the formation of clusters that are compact and roughly equal in size; when the distance metric is the minimum distance between the members of the targets, the algorithm encourages the formation of elongated clusters.

The ENN approach changes the principle of grouping after computing the distance between all targets. It links all the targets which the distance metrics are in the range of cluster as a group. Each target in the cluster will be chosen as a center to expand the cluster by changing the limit value intelligently. The process repeats until a single target remains.

(b) means the ENN. Grouping begins with the target. A few targets will be added in the grouping in the same step.

B. FR-ENN ALGORITHM

A novel algorithm is proposed based on the formational recognition and extend nearest neighbor approach which is named FR-ENN. The calculation steps are described as follows. Let \( S = \{O_1, O_2, ..., O_n\} \) be the present target set.

\( O_i = \{id, attr, location, course, type\} \) is an n-tuple containing multiple target attributes. Where \( id \) represents the number of target point, \( attr \) represents the attribute of hostile-side, friendside, location represents the space coordinate information, course represents direction of the target movement, type represents the model about target. Based on above definition, FR-ENN algorithm is:

**step1.** At \( t_1 \) time, select one target \( O_j \) as the first member of the cluster \( C_k \), \( (k = 1, 2, ..., i) \).

**step2.** Calculate the distance \( d_g \) between \( O_i \) and \( O_j \) which is in \( S \), \( (i \neq j = 1, 2, ..., n) \).

**step3.** Measure \( O_j \) as the follow principles, (a) \( d_g < \alpha \), where \( \alpha \) is a parameter. If \( O_j \) accord (a), (b), (c) join \( O_j \) in the \( C_k \) and delete \( O_j \) in the \( S \).

**step4.** select \( O_j \) as new center of \( C_k \), measure other target in the \( S \) with (a), (b), (c). add the target in the \( C_k \) which accord with (a), (b), (c) and delete it in the \( S \).

**step5.** measure all the members in the \( C_k \), if no new target is added in the \( C_k \), the expansible process stops.

**step6.** use the formational recognition method to calculate formation about \( C_k \) at \( t_1 \) time.

**step7.** calculate the same data about formation of \( C_k \) at \( t_2 \) time.

**step8.** compare the result about formation at \( t_1 \) and \( t_2 \) time. If result is smaller than \( \beta \), the grouping of \( C_k \) end. Else return step1.

**step9.** if \( S \) is not empty, select a new target in \( S \), return step1, else the algorithm ends.

V. SIMULATION EXPERIMENT

To evaluate the algorithm proposed in this paper, we created five different scenarios that were designed for situation
elements. The five scenarios are line formation, column formation, echelon formation, wedge formation and diamond formation.

![Figure 6. Different formational model](image)

We get the space coordinate information about each target from time T1 to T5. Grouping process will be finished by the FR-ENN and NN with the same data to every scenario with different first center target. The correct rate of grouping that is described as the following figure and table using the statistical method.

![Figure 7. Different formational right clustering rate](image)

It is seen from Figures 7 that, the right results are influenced by different formation and different first selected member. However, from Table 1 we can see that both of them in FR-ENN have high efficiency. When in real battle situation, FR-ENN algorithm will be seasoned with more scenarios.

Based on the results, it can be concluded that the correct grouping rate using the FR-ENN algorithm is better than that using the NN algorithm in all five scenarios. Especially in the line and column formation, our approach can achieve good grouping performance.

<table>
<thead>
<tr>
<th>Table 1. Correct rate of grouping</th>
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<tbody>
<tr>
<td>method</td>
</tr>
<tr>
<td>FR_ENN</td>
</tr>
<tr>
<td>NN</td>
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<tr>
<td>improve</td>
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</tbody>
</table>
We compared the accuracy of the two algorithms in Figure 7. The result presented are based on 10 frame runs. For the first few frame, target track is not steady, so right rate of both method are not high. With the frames going, grouping results are turning better and better. However, it can be abviously noticed that our method perfomance better than NN at every frame.

For farther comparing algorithms with efficiency, we tested the using time for target clustering created by five scenarios. We finally calculated average group formation time about each scenario. Based on the experimental result illustrated in Figure 8, we can conclude that the FR-ENN approach proposed in this paper always achieves better performance in time than the other in 1 to 5 scenario where 1 means line formation, 2 means column formation, 3 means echelon formation, 4 means wedge formation and 5 means diamond formation. In conclusion, the algorithm presented in this paper is better than NN in both accuracy and efficiency.

VI. CONCLUSIONS

In this paper, a novel target clustering approach called recognition-extend nearest neighbor (FR-ENN) is proposed. FR-ENN can be regarded as a refined method which can substantially improve the grouping performance. The core idea of the proposed algorithm is to group the relative targets by changing the limit value intelligently and recognize the battle formation with the triangular character recognition. Experimental results based on five scenarios (line formation, column formation, echelon formation, wedge formation and diamond formation) show that FR-ENN is an effective target clustering approach.

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