An Information Fusion Architecture for Situation Assessment of Ground Battlefield

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Abstract. The information fusion architecture for situation assessment is designed in the paper, which is divided into three stages: perception, comprehension and projection. The process of force structure classification is an important part which includes target aggregation region partition, command post recognition and force structure classification. The algorithm of template matching is proposed for the recognition of command post and force structure. Thus, the ground situation assessment is made in terms of concepts that can be computed. Finally, the simulation system of situation assessment is developed, a seaboard defense scenario is simulated and the situation assessment for the seaboard is analyzed to illustrate the functionality of the proposed model.

Keywords: Situation assessment, ground battlefield awareness, template matching.

1 Introduction

In recent years, decision-making in real-time dynamic battlefield is becoming increasingly complex due to the nature and diversity of threats and tactics that may be encountered. With enormous amounts of information available for command decisions, C4ISR system is required of the capability for situation assessment, which can help commanders form appropriate perception, timely and exactly understanding of battlefield situation. Situation assessment (SA) is the process of inferring relevant information about forces of concern in a battlefield, including location, movement and deployment of enemy forces, which is needed by the campaign commanders or analysts to support decision-making [1, 2].

Situation assessment is belonging to high-level information fusion, which goals include identifying the meaningful events and activities, deriving higher order relations among objects and inferring the intension. Over the course of the last two decades there have been several definitions of situation assessment proposed. The most widely accepted definitions are Dr. Mica Endsley's [3] and the Joint Development Laboratory (JDL) fusion model [4, 5]. Endsley's view is based on cognitive principles, which divides SA into three levels: perceiving elements in the environment within a volume of space and time; comprehending what they mean in context; and predicting their status in the near future. On the other hand, the JDL model provides a function data centric approach, which has 5 levels: Level 0-Sub-Object Identification; Level 1-Object Identification; Level 2-Situation Assessment; Level 3-Threat Assessment; Level 4-Process Refinement. With the JDL data fusion model, situation assessment falls in level 2 and accepts the results from level 1.

Situation assessment is a complex domain, especially for ground battlefield. Today, the modern battlefield is characterized by an overwhelming volume of information collected from a vast networked array of increasingly more sophisticated sensors and technologically equipped troops. There remains a significant need for higher levels of information fusion such as those required for generic situation assessment, prediction of enemy coursed of action (COA) and potential threat. For roughly 10 years, the research community has been recognizing the need for significant progress in this domain. Some researchers have proposed a few of methods and models for situation assessment, which includes fuzzy reasoning and theory [6, 7], Bayesian networks [8, 9, 10], template matching [11, 12], case-based reasoning [13, 14], ontology-based system [15, 16, 17], etc. Some researchers [18, 19, 20] have advocated the considerations of the battlefield intelligence in situation assessment, which provides some good illustrations of the complexity of gathering and processing intelligence in the practical applications.

In this paper, the problem of ground battlefield awareness is discussed. The rest of the paper is organized as follows. Section 2 provides an overview of the information fusion architecture for ground battlefield. Section 3 presents the process of force structure and deployment recognition, and the template matching algorithm is given. Section 4 illustrates a demonstration scenario of the coastal defense plan, and the results of situation assessment are given. Section 5 concludes this paper and presents some prospects for future work.

2 Overview of the Information Fusion Architecture

The process of situation assessment for ground battlefield is complex, nonlinear and replete with human interpretation and judgment. Therefore, the construction of computational models that infers the enemy courses of action (COA) and comprehends what have happened in the context is an extremely challenging task. In this section, we will provide an overview of the information fusion architecture for ground battlefield. The architecture is based on Endsley's model of SA with stages for perception, comprehension and projection. In Fig.1, the fusion architecture of ground battlefield awareness is presented.

(1) Event extraction: In the battlefield, there are various sensors deployed to scan an area of stationary or moving targets. Based on the output of sensors, we can obtain the different intelligence of ground battlefield. With the characteristics of the raw intelligence data, we can identify meaningful events and activities, such as appearance of important target, radio signal, fortification, force activity and so on. This is the first fusion level of

the architecture, which can be viewed as the phase of perceiving elements in the battlefield. Fuzzy theory and template matching are used in this level.

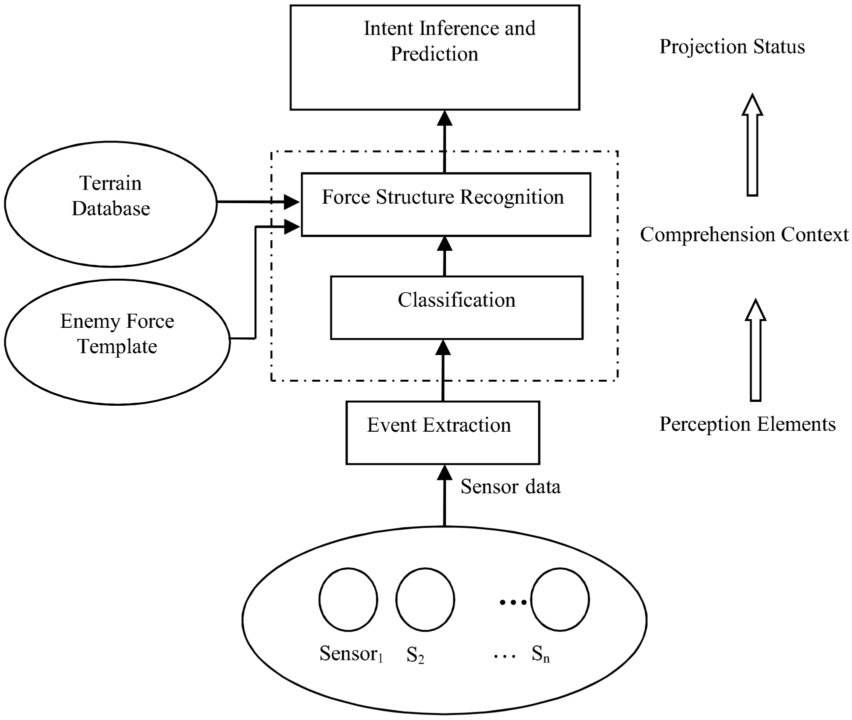

Fig.1. The architecture of ground battlefield awareness.

(2) Force structure recognition: To make awareness of ground battlefield, not only the individual targets should be identified, but also higher order relations among the different objects must be derived. Force group classification and recognition can explain the force composition, dynamic deployment and its intension, which is of great importance in the military decision making process. With the information on targets as well as terrain characteristics, the process of force structure recognition can interpret the relations among objects. Under force structure recognition, our effort is to obtain the results which can explain the following problems: ①who is there? ②what is their organizational group structure and posture? ③what are relative relations between group and its neighbors? ④what are their intensions?

(3) Intent inference and prediction: The process of intent inference and prediction is termed as the third level of fusion architecture, which predicts enemy force status in the near future. It takes as input the result of force structure recognition, some additional intelligence and infers enemy intension according to enemy doctrinal templates. In the

ground battlefield, the enemy intent inference is a very challenging problem, for the high degree uncertainty of observations. Most computational approaches to the intent inference are based on artificial intelligence, for example, D-S theory, dynamic Bayesian networks, fuzzy reasoning, etc. In the paper, this part is not discussed in the following.

(4) Enemy structure template: An enemy structure template depicts the composition and deployment of various types of sub-echelons or forces. For example, a brigade of artillery consists of several battalions, artillery. The expert knowledge base should be constructed for different level of force structure, which is used to recognize the enemy force structure.

(5) Terrain database: The terrain data is stored in the terrain database, which represents the terrain characteristics and traffic facilities: elevation, slopes, down-country, vegetation, body of water, road, railway, etc. The terrain data, used by force structure recognition, can make our analytical approach and methods available to the ground battlefield. The format of terrain data is based on a sampling of every N meters of terrain from a reference map, a rectangular mesh that includes significant information: elevation, road, river, and so on. Terrain analysis is essential in the process of determining enemy force group, including tactically important terrain characteristics, traffic ability patterns, and key terrain.

3 Force Structure Recognition

3.1 Intelligence Report

One of the challenges at the heart of this paper is analyzing large volumes of battlefield intelligence with the intention of figuring out what the enemy is doing and what type of threat such activities might represent. The intelligence reports are derived from various forms of physical sensors as well as by direct human observations. In the process of intelligence report analysis, some questions can be explained, for example, "what the enemy unit is doing?", "where are the important fortification in the ground battlefield?", and so on.

As intelligence reports come from the battlefield, the information it contains needs to be analyzed in the context, which is very important for situation assessment in ground battlefield. After event extraction from intelligence reports, we can identify some meaningful battlefield events. We now turn attention to the dimensions or attributes of the event from intelligence data, which includes: (1)Object: the object described in intelligence report, for example, command car, radio signal, fortification; (2)Size: the number of observed vehicles, the level of enemy force which can be equated with echelon level(e.g., squad, platoon, company); (3) Location: the location of the observed units in terms of latitude/longitude; (4) Time: the time of the observation; (5) Features: the features of target, such as a list of all the observed equipment the enemy is occupied, activity which denotes what the enemy force is doing, parameters of radio signal.

For different type of intelligence report, it can be represented by the formulation:

$$Intel_i = (K_i, S_i, T_i, F_i) \tag{1}$$

where K_i represents the observed object in intelligence report, such as enemy force, fortification, radio signal. S_i denotes the size of enemy force or the number of vehicles, and T_i represents the time of intelligence. F_i denotes the feature of the observed object. For the different type of object, the representation of feature is different.

3.2 Processing of Force Classification

According to the characteristics of ground battlefield, we give the process of force structure classification in the following:

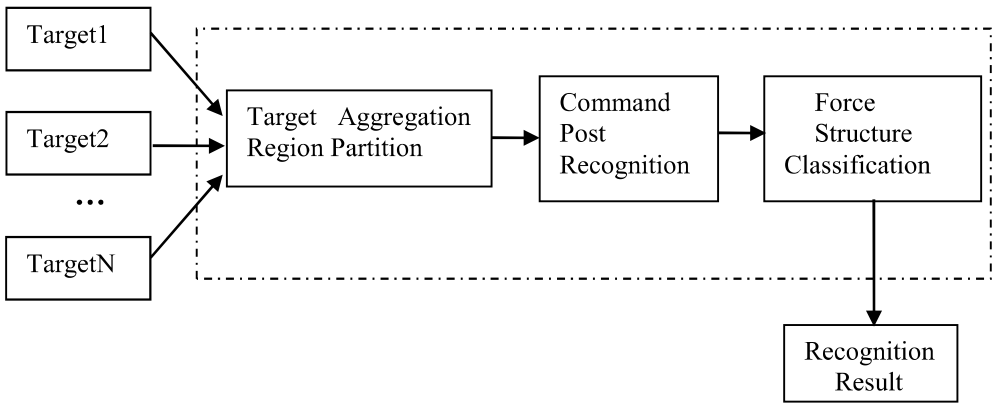

Fig.2. The process of force structure recognition.

(1) Target aggregation region partition: In the process of force structure recognition, we firstly divide the region of war into several parts based on military rules and battlefield target. For example, the region partition for the brigade command post is shown in Fig. 3.

According to general military rules, the brigade command post locates rectangular region (abcd) shown in Fig. 3. To get the position of the command post, the region (abcd) is partitioned into grid cell by 500*500(meter). Based on the twenty-four grid cells, the analysis can be made of the command post existence in the partitioned region (abcd). During the command post analysis process, the following information is utilized: terrain feature of a sampled cell, battlefield intelligence, and military rules.

(2) Command post recognition: After the partition of war region, we can analyze whether there is command post based on the military rules in the region. If the analysis shows the existence of command post, then the type of enemy force should be identified, e.g. tank platoon, company. Otherwise, the recognition of enemy force will be not performed in the partitioned region.

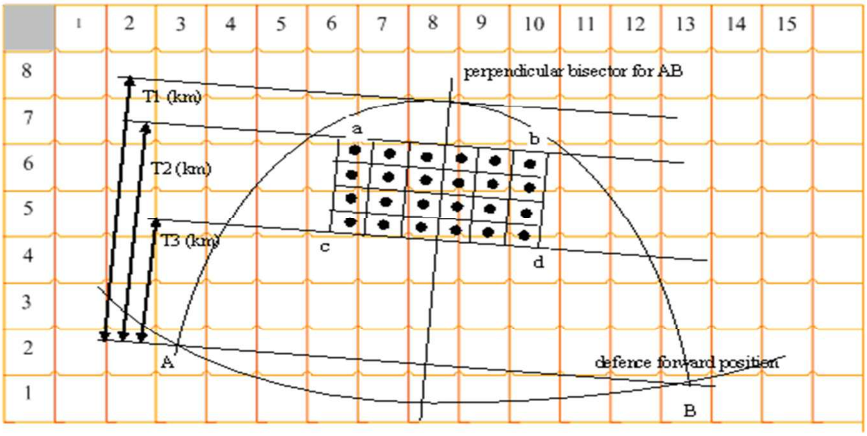

Fig.3. The region partition for the brigade command post.

On the process of recognizing the command post, the knowledge model is utilized to identify the type of command post. The knowledge model is based on some military knowledge, which is comprised of three parts: Position rule, Terrain characteristic, Intelligence symptom. For illustrative purpose, the knowledge model of brigade command post is described concisely in Fig.4.

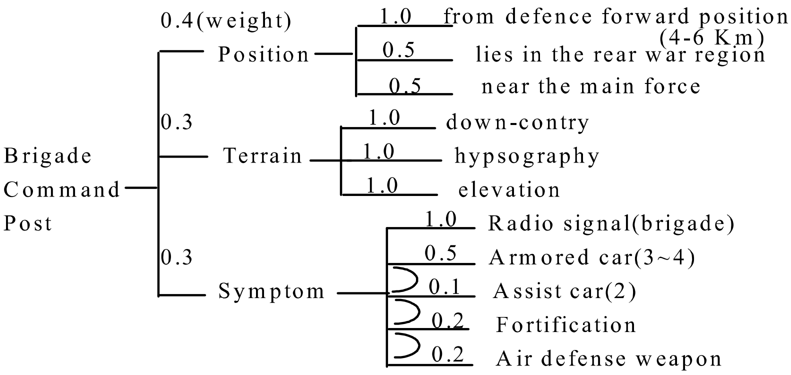

Fig.4. The knowledge model for the brigade command post.

According to the knowledge model, we can calculate the belief of the type of command post, which is defined by

$$Belief = W_1 \times Pbelief + W_2 \times Tbelief + W_3 \times Sbelief \quad (2)$$

where $Pbelief$ denotes the belief of position according to corresponding military rules, $Tbelief$ is the belief of terrain characteristic, $Sbelief$ is the belief of intelligence report, W_1, W_2, W_3 are the weights that are standardized to sum to unity.

(3) Force structure classification: To make useful predictions about the enemy intension, we should cluster the battlefield entities into higher level force aggregates based on the result of command post recognition. Similarly, expert knowledge model for force structure are used to match the various clusters so as to classify the aggregates into known classes of force structure. In the paper, the template matching method is utilized to classify the force structure.

3.3 Algorithm for Template Matching

A doctrinal template of force structure depicts the characteristic and deployment of various types of sub-echelons or vehicles. For example, a brigade consists of several battalions and some weapons. In general, a brigade should be deployed in the suitable area. So the template of brigade is comprised of three parts: terrain characteristics, the position of battalion, and intelligence reports for force, weapons and fortification, which is similar to knowledge model shown in Fig.4. Then the template of brigade can be represented as:

$$T = \{Rule, Terrain, Intel\} \quad (3)$$

where $Rule$ is the military rules for the brigade deployment, $Terrain$ denotes the terrain characteristics, and $Intel$ is the intelligence reports for the brigade.

For different levels of force, the constituent structure of each template is the same as the template of brigade. We can identify the type of force structure based on the force template matching. The algorithm of template matching includes: position rules matching, terrain characteristic matching and the matching of intelligence report. The matching process attempts to maximize the matching degree between a template and the enemy force. The process returns the template with the maximum matching degree.

For the two parts in the template: terrain characteristics, rule for the position of force, the matching algorithm is simple. We assume that for a given location *L*, there are enemy forces, e.g., two platoons. If the given location *L* is correspondent with the i-th rule in the template, the matching degree for part rule $Rule$ is calculated as:

$$Bel_R = Bel_R + W_{Ri} \times 1.0 \quad (4)$$

where W_{Ri} is the weight value of the i-th rule in the template and all the weights are standardized to sum to unity. Similarly, the matching degree for terrain characteristic Bel_T can be calculated by (4). For example, the force deployment area contains the features, such as a river, road, and elevation. And if the area terrain features is correspondent with the terrain characteristic in the template, then $Bel_T = Bel_T + W_{Ti} \times 1.0$.

In the intelligence part of force structure template, the fuzzy number is utilized to describe the number of target, e.g., approximate three command cars, approximate two platoon of enemy force. Then, fuzzy theory is used to match the ground intelligence report with the force template.

We assume that the membership function of the fuzzy number $\underset{\sim}{n}$ in the template can be defined as:

$$\mu_{\underset{\sim}{n}}(x) = \begin{cases} x - t_1, & t_1 \le x \le n \\ t_2 - x, & n < x \le t_2 \end{cases} \tag{5}$$

where t_1 can be given as $n-1$ or $n-2$, then t_2 is given $n+1$ or $n+2$. The membership function is represented by Fig.4.

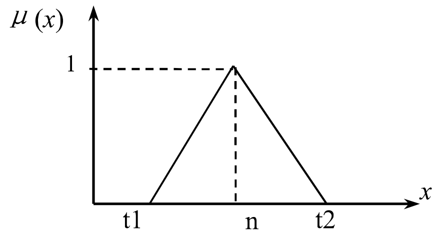

Fig.4. The fuzzy member of $\underset{\sim}{n}$.

If the target type in the intelligence report $Intel_i$ is matched with the type in the intelligence part of template T_k, then we can calculate the degree of match $\delta(Intel_i, T_k)$ between $Intel_i$ and T_k as

$$\delta(Intel_i, T_k) = w_1 \times m\_Bel_i + w_2 \times \mu_{\underset{\sim}{n}}(m) \tag{6}$$

where m_Bel_i is the mean belief value for the type of target in the $Intel_i$, m is the number of target in the intelligence report, $\mu_{\underset{\sim}{n}}$ is the member function of $\underset{\sim}{n}$ in the template, w_1, w_2 respectively denote the importance weight of target type, number in the template T_k.

Algorithm1 describes the process of matching with force structure template, where the matching degree δ is initialized as '0'. The template with the maximum matching degree which is greater than the threshold value σ is returned by the matching process. The algorithm can also be used to match command post, e.g. a command post of brigade.

Algorithm 1. Template Matching Algorithm.

1: Initialize $\delta_k = 0$, and the templates for matching: $\{T_1, T_2, ..., T_n\}$

2: For rules of force deployment(position), the matching degree is calculated as: $\delta(Location_i, T_k) = W_{Ri} \times 1.0$

3: For terrain characteristic, $\delta(Terrain_j, T_k) = W_{Tj} \times 1.0$

4: For intelligence report: $\delta(Intel_p, T_k) = w_{11} \times m\_Bel_p + w_{12} \times \mu_{\underline{n}}(m)$

5: Update the total matching degree as necessary:

$$\delta_k = W_R \sum \delta(Location_i, T_k) + W_T \sum \delta(Terrain_j, T_k) + W_I \sum \delta(Intel_p, T_k)$$

where $W_R + W_T + W_I = 1$. If the value of $\sum \delta(Intel_p, T_k)$ is greater than '1', then the value is set '1'.

6: Determine the δ_k is maximum matching degree and greater than the threshold σ, then return template T_k.

4 Simulation and Results

The simulation system, the essential part of information fusion project, is developed to demonstrate the process of ground battlefield awareness, which is comprised of four parts: intelligence editor, command post recognition, force structure analysis, template database and terrain database. The relation of the different parts in the simulation system is shown in Fig. 5.

We developed the intelligence editor in order to add the ground battlefield intelligence report into the simulation system. The type of intelligence includes force activity, fortification, vehicles, radio signal and so on. The intelligence data is comprised of the type of object, the size or number of object, the position, the object feature and the received time. The data of terrain characteristic is stored in the terrain database. The corresponding database editor is also developed for terrain data maintenance. The results of situation assessment are displayed on a traditional map.

For the purpose of showing the simulation process of situation assessment, let's consider the following scenario: there is a conflict in the sea, and the enemy attempt to attack our domain. They deployed some force in the seaboard. To destroy their plan, we should analyze the enemy force deployment and the force structure. According to the terrain features, received intelligence report and other sensor data, the situation assessment for the seaboard can be analyzed.

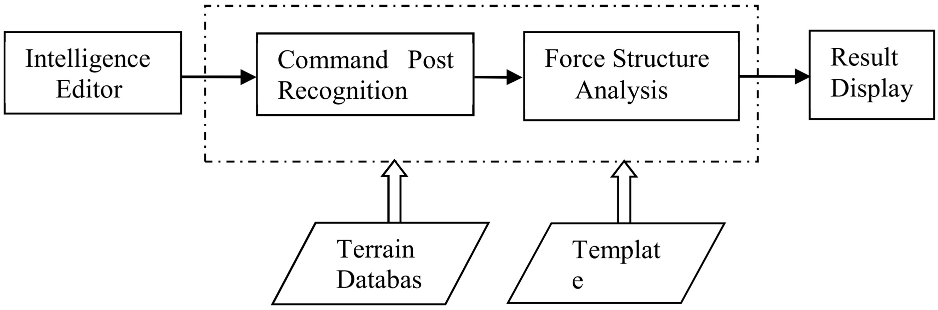

Fig.5. The structure of simulation system.

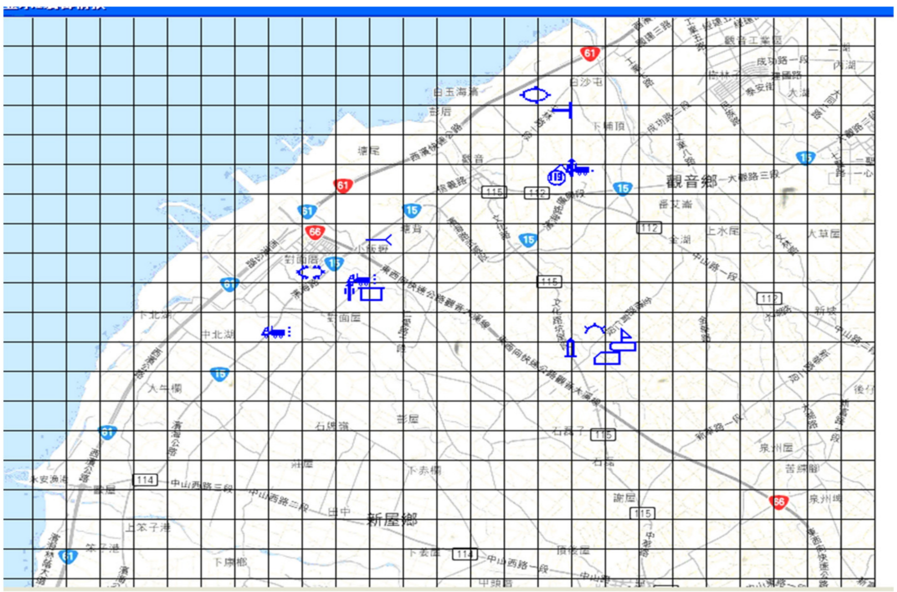

Fig.6. The result of intelligence edition for situation assessment.

4.1 Intelligence Editor

The intelligence editor is used to demonstrate the fusion of ground battlefield intelligence report. It is a software tool that can edit the intelligence for ground battlefield awareness.

An example edition result of the tool is shown in Fig.6. We can add, delete, or update an intelligence object which is shown by blue color on the map, such as command car, fortification. Then the intelligence report can be generated according to the edition result, and saved in a file by defined data format. While the simulation of battlefield situation assessment, the intelligence report is read from the corresponding file and sent to the module of command post recognition or force structure analysis by the order of the received time.

Similarly, some intelligence reports are edited for the simulation scenario. Table 1 describes the object of each intelligence report and the number or size of the object.

Table 1. The intelligence reports in the simulation scenario.

Intelligence No.	Target	Size/number	Position(x,y)
1	Armored car	3~4	(9233,5466)
2	Air defense rocket	2	(6366,2600)
3	Fortification		(8933,5350)
4	Assist car	3~5	(9033,5750)
5	Grenade launch base		(3833,5216)
6	Air defense rocket	2	(3933,4166)
7	Assist car	4~5	(9450,2850)
8	Fortification		(9283,3066)
9	Radio signal(battalion)		(5450,5400)
10	Air defense weapon		(9150,2800)
11	Fortification		(7200,3583)

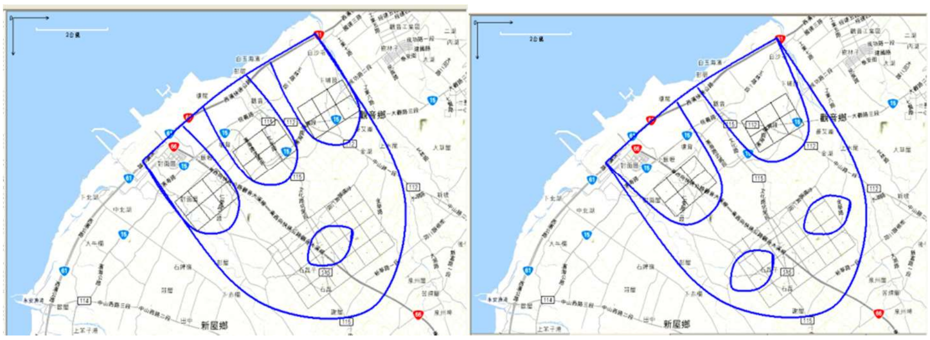

Fig.7. The results of target aggregation region partition

4.2 Command post Recognition

The command post recognition is the first step in the ground situation assessment. It includes region partition for command post, and data fusion of sensors, intelligence, terrain etc. According to military rules, the war region in the seaboard can be partitioned into two results, which is shown in Fig.7.

a: partition 1 **b:** partition 2

In Fig. 7, the rectangular grid cell is used to recognize the command post. In the front, the grid cells are used for battalion command post. And in the rear region, the grid cell is used for brigade command post. According to the brigade and battalion command post knowledge models, we can use the template matching algorithm to identify whether there exits command post. In the process of template matching, the sensor data, terrain characteristic, intelligence report are fused. If the degree of template matching is greater than the threshold σ, we can identify the type of command post. Otherwise, we can infer there does not exit command post. The threshold σ for command post template matching is set by 0.7.

In this simulation scenario, the templates for brigade and battalion command post are respectively utilized. The results show that the command post matching degrees of Fig. 7(a) are greater than Fig. 7(b). Furthermore, the matching degrees of both battalion and brigade command post in Fig. 7(a) are all greater than threshold σ (0.7). Table 2 describes the matching degree of each command post in Fig. 7(a).

Table 2. The result of template matching for command post in Fig. 7(a).

Command Post	Position rule	Terrain characteristic	Intelligence symptom	Matching degree
Brigade command post 1	1.0	1.0	0.77	0.93
Brigade command post 2	1.0	1.0	0.68	0.90
Brigade command post 3	1.0	1.0	1.0	1.0
Battalion command post	1.0	1.0	0.85	0.95

(The sequence of brigade command post 1,2,3 is from right to left.)

In table 2, the columns of position rule, terrain characteristic, intelligence symptom respectively denotes position rules matching, terrain characteristic matching and the matching of intelligence report. The last column represents the total matching degree which is a tradeoff for the three template matching part.

4.3 Force Structure Analysis

In the next step, we can analyze the force structure according to the results of command post recognition. Thus, the analysis is made based on the result of Fig. 7(a). The force structure templates are used in this step, and the template matching algorithm described as section 4.3 is implemented. In this simulation example, the result of force structure analysis is shown in Fig. 8.

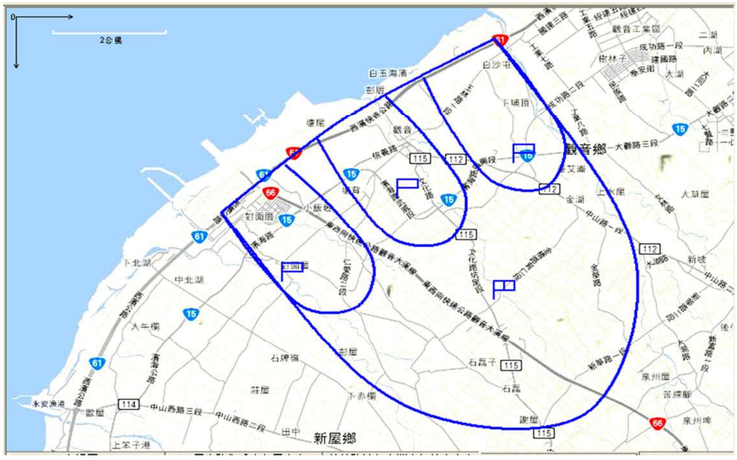

Fig.8. The result of force structure analysis.

The deployment of enemy force is approximately illustrated in Fig.8, which template matching degree is great than 0.60. There are three battalions in the forward position which is represented by blue arc, and each battalion command post is located which is shown by blue flag. In the rear area, the blue flag represents the brigade command post. Furthermore, the analysis can give the detail features of the deployment, such as the location of battalion or brigade, the width value and depth value.

5 Conclusion

We presented architecture and its implemented computational embodiment for situation assessment of ground battlefield. The architecture can fuse intelligence from sensor data, terrain characteristic, and military knowledge in a coherent system. The force structure is analyzed and computed, which can be shown in the simulation system of situation assessment.

In the future work, we plan to explore the model of tactical goal hypothesis generation and inference. In addition, we will extend our architecture of situation assessment to predict the future significant feature of battlefield.

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