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# A Novel Algorithm to Ground Formation Tracking

Ronghua Guo *, Shiping Xu, Chengdong Huang and Haipeng Fu

*Unit of 63880, Luoyang, Henan, 471003, China*

**Abstract**

A logical method of ground formation target tracking, which includes formation initiation, formation separation, formation merging and formation updating, is proposed according to the kinetics of formation moving. The method addresses the problem of multi-targets tracking as a whole by using the centre -based tracking approach in the process of track updating. Therefore, it is practicable due to reducing the computational burden and saving system resources.



*Keywords:* Formation target tracking; Formation; Centre of a formation

## 1. Introduction

A group of targets are required to keep in a formation for tactical purposes or task requirements, such as a robot formation, an aircraft formation, a satellite formation and a vehicle formation. The method of formation target tracking and controlling can reduce the system cost, increase the system robustness and efficiency. Therefore, it has reconfiguration ability and structure flexibility for the system. Formation control has wide applications, for example, security patrols, search and rescue in hazardous environment, area coverage and reconnaissance in military tasks (Chen and Wang, 2005).

The problem of tracking ground formation targets including military equipments and civil vehicles is more difficult than that of tracking air targets. This is because of a relatively close distance between ground targets,

* Corresponding author. Tel.: +86-379-88856966; fax: +86-379-88856966.
*E-mail address:*guorh05@gmail.com.


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the movement uncertainty and the complexity of radar echoes' environment. Bar-Shalom et al. (Bar-Shalom, 1978; Bar-Shalom et al., 2001) proposed the concept of "clutter" and treated a "clutter" as a group, and had done a lot of research. In recent years, formation tracking and controlling technology has gradually become a very active research topic with broad applications in the formation of aerospace, robotics, marine vessels and ground vehicles.

A logical method of formation target tracking, which includes formation initiation, formation separation, formation merging and formation updating, is proposed according to the kinetics of formation moving. A FC-IMM-UPF algorithm is applied to address formation target tracking (Bilik I and Tabrikian J, 2010; Ronghua G, etl., 2007).

## 2. A method of formation tracking

### *2.1. The maintenance of a formation*

Formation target tracking maintenance can choose the minimum bounding rectangle and the minimum circumscribed circle of formation or the geometry centre of the smallest closures, and use the geometric centre tracking method to track and maintain formations. When formation combining, we can amend the geometric centre of the formation. Because when a new target enters, the correlated area of formation target will change. If we continue to use the original centre, it is inaccurate to track new formation targets. Therefore, we should amend the centre of new formation targets. Then we take the minimum bounding rectangle of formation target as an example, and describe the identification and evolutionary relationships of formation spatial structure in detail. For the bounding rectangle of formation targets, length and width always remain parallel to respectively *X*-axis and *Y*-axis of Cartesian coordinate system.

1. Determine target prediction of the minimum bounding rectangle. Whether multiple targets are in a straight line or not, the processing approach is the same for three or more targets. A formation is assumed to be composed of *N* targets, and their geometric centre is shown in Fig. 1. The 2-D Cartesian coordinates position vectors of *N* targets are denoted respectively as $T_1(x_1, y_1)$, …, $T_i(x_i, y_i)$, …, $T_N(x_N, y_N)$. The four vertices of the minimum rectangle of target predicted positions are denoted respectively as $A(x_a, y_a)$, $B(x_b, y_b)$, $C(x_c, y_c)$ and $D(x_d, y_d)$, and the centre is denoted as $O(x_O, y_O)$. Then,

$$\begin{aligned} x_a = x_d = \min\{x_1,\ x_2,\dots,x_N\} \qquad x_b = x_c = \max\{x_1,\ x_2,\dots,x_N\} \\ y_a = y_b = \min\{y_1,\ y_2,\dots,y_N\} \qquad y_c = y_d = \max\{y_1,\ y_2,\dots,y_N\} \end{aligned} \tag{1}$$

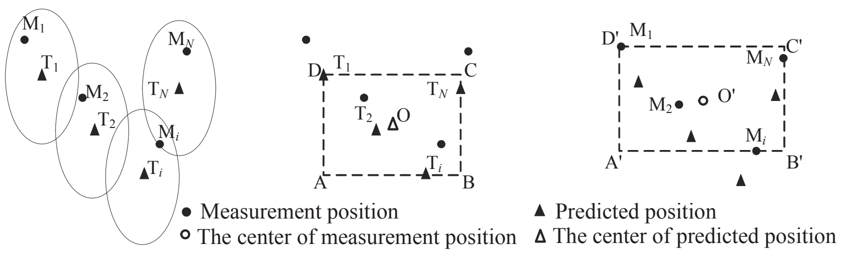



Fig. 1. Determine the minimum enclosing rectangle of target predicted and measurement positions, and their geometric centre

2. Determine the centre of the minimum enclosing rectangle of target predicted positions. According to the four vertices of the rectangle, the geometric centre is determined by

$$x_O = x_a + (x_b - x_a)/2 \qquad y_O = y_a + (y_c - y_a)/2 \tag{2}$$

3. Establish the corresponding relationship between the centre and each target in the formation.

The relationship between the rectangular geometric centre O($x_O$, $y_O$) and the ith target in the formation may be denoted by the coordinate offset $\Delta x_i$=[$\Delta x_i$, $\Delta y_i$], which is given by

$$\Delta x_i = x_O - x_i \qquad \Delta y_i = y_O - y_i \tag{3}$$

That is to say, $T_i \rightarrow$ O: [$\Delta x_i$, $\Delta y_i$]. Therefore, the corresponding relationship between the centre O and all targets in the formation is represented as

$$T_i \rightarrow O\text{: } \{[\Delta x_1, \Delta y_1], \cdots, [\Delta x_i, \Delta y_i], \cdots, [\Delta x_N, \Delta y_N]\} \quad i=1,2,...,N \tag{4}$$

4. Compute the predicted position of each target at next time with the coordinate offset. Several symbols are defined as follows: $T_{i,k}(x_{i,k}, y_{i,k})$ , the predicted position of the *i*th target at time *k*; $M_{i,k}(x'_{i,k}, y'_{i,k})$ , the measurement position of the *i*th target at time *k*; $O_k(x_{O,k}, y_{O,k})$ , the minimum enclosing rectangle centre of a formation's predictions at time *k*; $O'_k(x'_{O',k}, y'_{O',k})$ , the minimum enclosing rectangle centre of a formation's measurements at time *k*.

Starting from time *k*, the estimated position of the centre will move from $O_k$ to $O_{k+1}$ when the formation forwards a time step *T*. The predicted minimum enclosing rectangle centre of a formation at time *k*+1 is denoted as $O_{k+1}(x_{O,k+1}, y_{O,k+1})$. The evolution of the prediction centre of a formation is shown in Fig. 2.

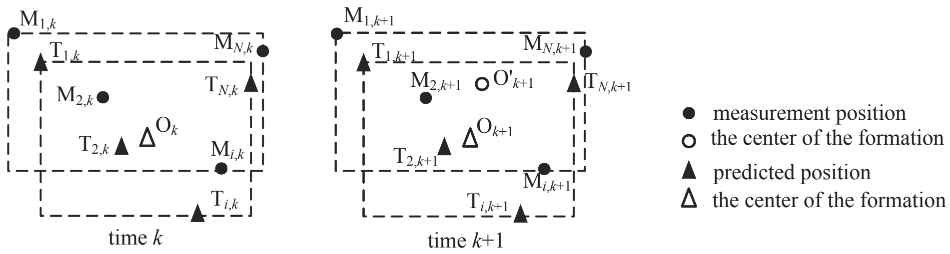



Fig. 2. The evolution of the prediction centre of a formation

Under the premise of maintaining the stability of spatial structure in the continuous tracking phase, the tracking approach based on minimum enclosing rectangle centre of a formation based is applied to predict the rectangular centre at time *k*+1. Then, the estimated position vector of each target at time *k*+1 is calculated by the measurement of the minimum enclosing rectangle centre at time *k*+1, the prediction $O_{k+1}(x_{O,k+1}, y_{O,k+1})$ at time *k*+1, and the corresponding relationship between the centre and all targets in the formation.

$$x_{i,k+1} = x_{O,k+1} - \Delta x_i \qquad y_{i,k+1} = y_{O,k+1} - \Delta y_i \tag{5}$$

5. Deal with the target measurement. Similar to deal with the target prediction, the measurements are processed as follows. The minimum enclosing rectangle and its centre are determined at first; then the corresponding relationship between the centre and all measurements in the formation.

## *2.2. The separation and combination of a formation*

The separation and combination of a formation both belong to the formation logical process. To describe the algorithm of the formation separation and combination, some symbols are defined in Table 2.

1. The algorithm of formation separation

(1) If $F_j(d_i) > F_j(r)$ and $T_j(d_i) < T_j(r)$, we separate the target *i* from the formation and make it forms a new target, which will be involved in the combination process.

(2) If the extrapolation tracking times of targets in formation go beyond the fixed value (NoRelationCounter(*i*) $\geqslant m$ or $T_j(d_i) > T_j(r)$), we separate the target from the formation and drop it.

2. The algorithm of formation combination

(1) Initialize the formation, ensuring that every formation only correlates a target.

(2) If a new target is discovered, we compute the shortest distance between the new target and the centre of all the tracking formation $\min\{F_{j*}(d_l)\}$.If $\min\{F_{j*}(d_l)\} < F_j(r)$, we append this target to the closest formation. Otherwise, we consider the target as a new formation, and the new target will be created by the slide window algorithm or the separation of the formation.

Table 1. An example of a table

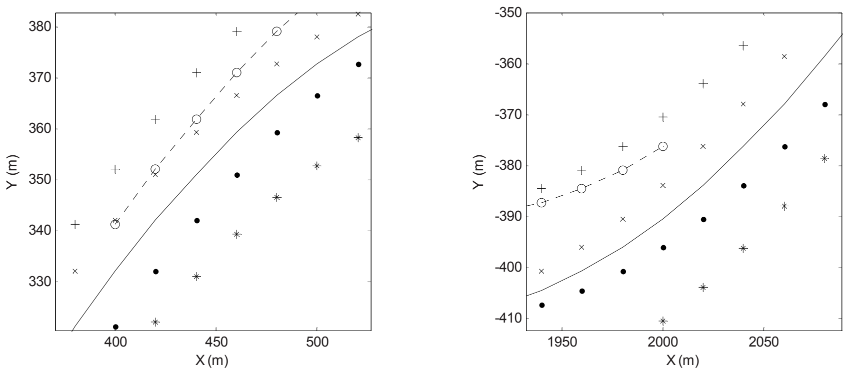
| Symbol | Definition |
|---|---|
| $F_j(r)$ | The longest radius of formation, $j$=1, 2, …, $M$ is the number of formation. |
| $F_j(d_i)$ | The distance between target $i$ and formation centre, $i$=1, 2, …, $N$ is the number of target. |
| $T_j(r)$ | The longest radius of formation tracking gate, $j$=1, 2, …, $M$ is the number of formation. |
| $T_j(d_i)$ | The distance between target $i$ and the centre of tracking gate. |
| $F_{j*}(d_l)$ | The distance between new target $l$ and the $j$*th formation centre, $j$*=1, 2, …, $M$ is the number of formation. |
| $\min\{F_{j*}(d_l)\}$ | The shortest distance between new target $i$ and all the target centre. |

## 3. Simulation and analysis

The algorithm is used to process maintaining of tracking to formation state, the augment of new target (the combination of formation) and the loss of target (the separation of formation). The formation tracking and multiple targets tracking methods are applied to deal with a tracking instance respectively, and analyze how the number of targets can affect the two different tracking methods. A CV and a CT model is used as the target movement model (Ronghua G, etl., 2007).

### *3.1. Simulation*

The targets in formation do snake-like mobile. When the formation target has moved for 20s, the new target (target 5) appears, and joins into the formation, which is shown in Fig. 3(a).When it has moved for 100s, the target 5 disappears from the formation, which is shown in Fig. 3(b). For the formation tracking algorithm, the number of particle $N$=200, the particle number of every model is set as 100.




(a) Target 5 appears and adds to the formation

(b) Target 5 disappears

Fig. 3. Target 5 appears and disappears in the formation

### 3.2. The computational complexity

In order to analyze how the number of formation target and the tracking methods (formation target tracking and multiple target tracking) can affect the time complexity, we set the number of formation target as five, ten and fifteen, computing the single-step computing time of target tracking respectively, which is shown as Table 2.The formation target tracking adopts the formation tracking algorithm, while the multiple target tracking adopts the multitarget tracking algorithm. When the number of targets is 5, the single-step computing time of multiple target tracking is 3.54 times of the formation target tracking. When the number is 10, the single-step computing time of multiple target tracking is 5.18 times of the formation target tracking. When the number of target is 15, the single-step computing time of multiple target tracking is 6.12 times of the formation target tracking. So it is clear that, as the increase of the targets number, the efficiency of formation tracking is higher. And compared with the multiple targets tracking, the advantage of formation tracking is obvious.

Table 2 A comparison of computing time for the number of targets in a formation and tracking mode

| Tracking mode | The target number of a formation (Single-step time (ms)) | | |
|---|---|---|---|
| | 5 | 10 | 15 |
| Formation | 3 | 4.128 | 5.248 |
| Multi-target | 10.624 | 21.376 | 32.12 |

## 4. Conclusion

We propose a FC-IMM-UPF formation target tracking algorithm based on geometric centre. In the engineering practice, this algorithm can implement the integrated tracking to the multiple targets. When targets join or lose, it can also work normally.

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