Construction of target track quality grading system

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ABSTRACT

Target track quality grading system plays an important and practical role in real-time evaluation of target trajectory quality and improvement of the target tracking accuracy of detection equipment. In the paper, the definition and distribution of target trajectory accuracy is introduced, and the multi-dimension trajectory state error is uniformly quantified using error sphere radius. Then the constructing process of target track quality grading system is designed. At last, simulations show the affection of grading thresholds and target trajectory accuracy calculation models on the construction of target track quality grading system.

Keywords: Tracking accuracy, error sphere radius, track quality grading

1. INTRODUCTION

Track quality (TQ) assessment of tactical data link is the key part of battle efficiency evaluation. The U.S. Army has defined the target track quality standard for Joint Tactical Information Distribution System (JTIDS), including air, marine, and land targets[1,2]. Based on the long-term and mass detecting data, the U.S. Army has designed and established the battlefield target track quality grading system[3].

The track quality grading system reflects the distribution of equipment detection accuracy, and is the basis for real-time target trajectory quality evaluation. Besides, the track quality grading system is used to evaluate the trajectory accuracy that can be achieved by equipment upgrade.

The calculation and classification of trajectory accuracy are crucial to track quality grading. The calculation of trajectory accuracy is mainly using position and velocity data[1,4-6]. This paper proposes a trajectory accuracy classification method based on 6-dimension position/velocity information, and presents a target track quality grading system construction method which is applicable for engineering applications.

The paper is organized as follows: Section 2 introduces the distribution and calculation model of trajectory accuracy, Section 3 illustrates the constructing process of track quality grading system, Section 4 analyzes the experimental results, and we conclude in Section 5.

2. DISTRIBUTION AND CALCULATION MODEL OF TRAJECTORY ACCURACY

2.1 Distribution and confidence level of trajectory accuracy

The target trajectory accuracy represents the degree of deviation between the sensors measured trajectory and target true trajectory. The target trajectory accuracy can be computed as the covariance of difference between the measured state and the true state:

$$cov\left(e(x),e(x)^T\right)=E[\left(e-E(e)\right)\left(e-E(e)\right)^T] \tag{1}$$

$$\mathrm{e}(\mathrm{x})=\hat{x}-x$$

$\hat{x}$ is the sensors measured target state, x is the true target state, $\mathrm{e}(\mathrm{x})$ is the target state error.

The second order statistics of target state error $\mathrm{e}(\mathrm{x})$ is $y=\mathrm{e}(\mathrm{x})\sum_m^{-1}e(x)^T$, which obeys the second order χ^2 distribution[4,7]:

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$$\mathrm{e}(\mathrm{x})\sum_{m}^{-1}e(x)^{T}\sim\chi^{2}(y,m) \tag{2}$$

$$\sum_{m}=\begin{bmatrix} cov(e(x_1),e(x_1)^T) & cov(e(x_1),e(x_2)^T) & \dots & cov\left(e(x_1),e(x_m)^T\right) \\ \dots & \dots & \dots & \dots \\ cov(e(x_m),e(x_1)^T) & cov(e(x_m),e(x_2)^T) & \dots & cov(e(x_m),e(x_m)^T) \end{bmatrix}$$

As is known to all, the relationship between confidence level and confidence interval of χ^2 distribution is:

$$\int_{0}^{k_\alpha(m)}\chi^{2}(\mathrm{y},\mathrm{m})\,\mathrm{dy}=1-\alpha \tag{3}$$

where α is the risk rate, 1-α is the confidence level, $k_\alpha(m)$ is the confidence interval, m is the dimension of a single sample, y is a statistic variable. The probability of y falls in [0, $k_\alpha(m)$] is 1-α.

For the battlefield target, 6-dimension measured trajectory data contains position x, y, z and speed v_x, v_y, v_z. According to χ^2 distribution table, when m=6 and 1-α=0.95, the confidence interval $k_\alpha(m)$ is:

$$k_\alpha(6)=12.59 \tag{4}$$

Using (3) and (4), when the second order statistics of 6-dimension state error falls in [0, 12.59], the corresponding probability is 95%.

2.2 Calculation model of trajectory accuracy

The calculation of trajectory accuracy is the quantitative basis of track quality grading system construction. By introducing error sphere and error sphere radius, multi-dimension target trajectory state error is computed using one sphere radius, thus simplifying the calculation of trajectory accuracy.

The 3-dimension trajectory state error radius is shown in Figure 1.

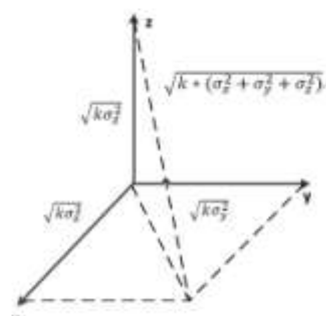


Figure 1. The 3-dimension trajectory state error radius.

When the confidence level is 0.95 and $k_\alpha(6)$ =12.59, the 6-dimension trajectory state error ellipse is:

$$\left(\mathrm{x},\mathrm{y},\mathrm{z},v_x,v_y,v_z\right)\begin{pmatrix} \sigma_x^2 & \sigma_{xy} & \sigma_{xz} & \sigma_{xv_x} & \sigma_{xv_y} & \sigma_{xv_z} \\ \sigma_{xy} & \sigma_y^2 & \sigma_{yz} & \sigma_{yv_x} & \sigma_{yv_y} & \sigma_{yv_z} \\ \sigma_{xz} & \sigma_{yz} & \sigma_z^2 & \sigma_{zv_x} & \sigma_{zv_y} & \sigma_{zv_z} \\ \sigma_{xv_x} & \sigma_{yv_x} & \sigma_{zv_x} & \sigma_{v_x}^2 & \sigma_{v_xv_y} & \sigma_{v_xv_z} \\ \sigma_{xv_y} & \sigma_{yv_y} & \sigma_{zv_y} & \sigma_{v_xv_y} & \sigma_{v_y}^2 & \sigma_{v_yv_z} \\ \sigma_{xv_z} & \sigma_{yv_z} & \sigma_{zv_z} & \sigma_{v_xv_z} & \sigma_{v_yv_z} & \sigma_{v_z}^2 \end{pmatrix}^{-1}\begin{pmatrix} x \\ y \\ z \\ v_x \\ v_y \\ v_z \end{pmatrix}=12.59 \tag{5}$$

where x, y, z and v_x, v_y, v_z represent the errors in position and velocity respectively. σ^2 represents the variance of state error. The probability of the 6-dimension target state error falling into the ellipse is 95%.

The error sphere radius derived from the 6-dimension trajectory state error ellipse is:

$$R_6 = \sqrt{12.59 * (\sigma_x^2 + \sigma_y^2 + \sigma_z^2 + \sigma_{v_x}^2 + \sigma_{v_y}^2 + \sigma_{v_z}^2)} \tag{6}$$

3. CONSTRUCTING PROCESS OF TRACK QUALITY GRADING SYSTEM

The trajectory classification method provides an optimal clustering of target trajectory error states. For p samples to be classified, each sample can be treated as a point in R^p space. The distance between samples is usually employed to measure the similarity[8,9]. The Euclidean distance is the most widely used distance of the Minkowski distance, and its main advantage is that the orthogonal rotation of the coordinate axis does not affect the calculation results of the Euclidean distance[10,11]. In this paper, Euclidean distance and the sum of squared deviations are used in the calculation of sample distance and class distance respectively[12].

Using the error sphere radius and the optimal clustering algorithm, the target track quality grading system can be established for practical engineering applications. The construction process of the target track quality grading system is shown in Figure 2.

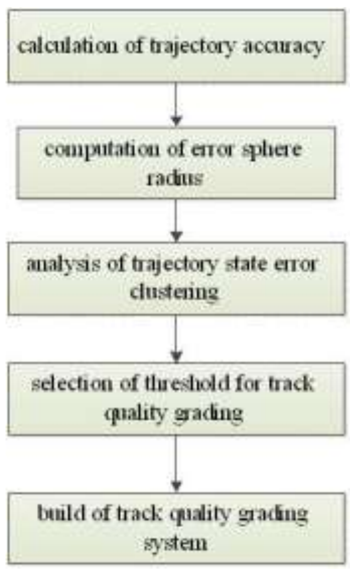


Figure 2. Constructing process of target track quality grading system.

(1) Calculation of trajectory accuracy: combining the accuracy indicators of sensors (e.g. distance, azimuth, elevation accuracy), target trajectory accuracy information generated by multi-source data fusion, navigation positioning information, etc., and then the trajectory accuracy information is obtained. Here, the trajectory accuracy information contains 6-dimension state error of position and velocity.

(2) Computation of error sphere radius: the variance of the 6-dimension position/velocity state error is calculated, and then the error sphere radius with a confidence level of 0.95 is computed.

(3) Analysis of trajectory state error clustering: using the classification method described in Section 3, the spatial distribution tree clustering diagram of trajectory state error is obtained. In this step, measurements of the same sensor in different ranges (such as distance) may cluster into different classes. The distribution of trajectory state error is analyzed for further selection of certain grading threshold.

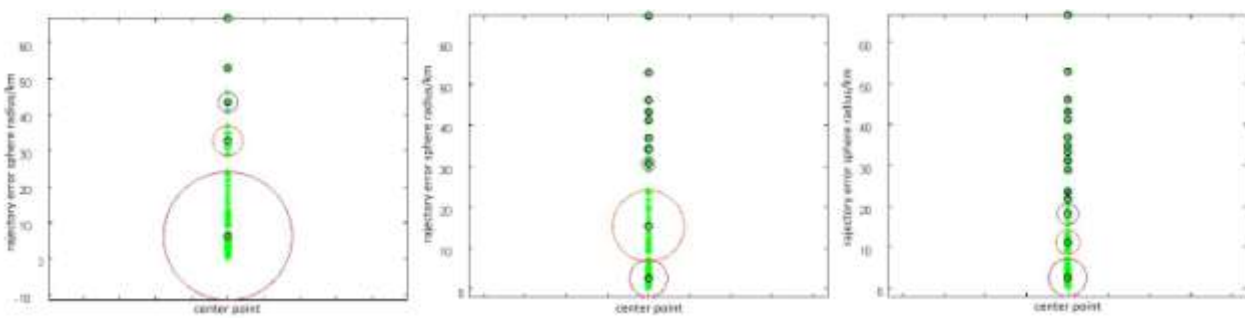
(4) Selection of threshold for track quality grading: based on the battlefield environment and different application requirements, sensor accuracy and target dynamic characteristics, as well as the trajectory state error tree clustering diagram obtained in step 3, a reasonable number of trajectory clusters is selected.

(5) Build of track quality grading system: the number of trajectory clusters determined in step 4 is used as the track quality grading number. For each track quality level, the boundary between each cluster as the comprehensive grading distance is set. The comprehensive ellipse generated by the multi-dimension track state error is replaced with sphere covered by the error radius, and finally the target track quality grading system is generated.

4. SIMULATION RESULTS

For the same target, 100 simulated trajectories of 5 sensors are generated as the sensors measured trajectory, and a simulated trajectory is also generated as the true trajectory in the experiment. The difference between the sensors measured trajectory and the true trajectory is obtained for track quality grading system construction.

Firstly, we choose three clustering numbers N(N=5, 10, 15), and obtain three different track state error classification results. Figure 3 shows the classification results using different clustering number.



(a) N=5 (b) N=10 (c) N=15

Figure 3. Classification results using different clustering number.

The green * represents the error sphere radius of trajectory samples. The black O represents the center point of each class, corresponding to the mean error sphere radius of each class.

It can be seen that the range of error sphere radius of the trajectory samples is 1.6-66.7 km. 12% samples are greater than 20 km and distributed between 20.5-66.7 km. The remaining 88% samples are distributed between 1.6-19.6 km, with relatively small distances between samples. Therefore, when the clustering number is 10 or 15, a sample with larger error sphere radius is mostly classified into one class separately.

As can be seen, the clusters after the 5th cluster are mostly reduced to a single point due to the small number of samples. Therefore, in order to obtain uniform and representative classification results as possible, we choose N=5 to establish a target track quality grading system. In practical engineering applications, it is necessary to set appropriate track quality classification threshold considering the specific application requirements, such as target accuracy, target state change rate, environment, and other conditions.

5. CONCLUSIONS

The method of constructing target track quality grading system is studied, especially the representation of trajectory state error and the optimal clustering algorithm. The error sphere radius is employed for the measurement of target trajectory error state. Furthermore, considering the trajectory accuracy distribution, the impact of different clustering numbers on classification is analyzed. When the trajectory accuracy distribution is sparse, a large clustering number may easily lead to individual samples becoming independent of each other, making the classification results too scattered and unrepresentative. The sparse trajectory accuracy distribution may be due to the calculation of the target trajectory error sphere radius, which ignores the differences between multi-dimension errors. To some extent, error sphere radius expands the range of the error ellipsoid, resulting in a more dispersed distribution. Therefore, more accurate methods for quantifying trajectory state errors are needed for future work.

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