Research on multi-targets real-time ballistic recognition method based on movement multiple feature correlation

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Research on multi-targets real-time ballistic recognition method based on movement multiple feature correlation

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Abstract. In the optical measurement of burst multi-targets such as the rocket, missile, bullet and so on, in order to solve the poor real-time reliability problem of the multi-targets ballistic recognition caused by the invalid ballistic recognition algorithm variable and less movement feature quantity, a multi-targets ballistic recognition method based on movement multiple feature correlation has been proposed, and the mathematical model algorithm and multi-targets real-time ballistic recognition strategy has been established at the same time. It has been proved that the method can improve the adaptability, real-time performance and reliability of multi-targets real-time ballistic recognition, to provide technical support to real-time multi-targets optical measurement and processing.

1. Introduction

In optical measurement, multi-target real-time trajectory recognition[1] is used to solve the real-time trajectory correspondence between multi-target points at different times. At present, the trajectory of multiple targets in the imaging target plane coordinate system is usually identified and processed by only considering the moving direction and velocity characteristics of the target. The intersection measurement of two devices is prone to problems such as coplanar and occlusion, etc. In addition, the algorithm based on the moving direction and velocity feature of multiple targets has low adaptability and reliability in real-time trajectory identification and processing for multiple targets under the condition that the moving direction and velocity feature of multiple targets are similar.

In order to solve the problem, a multi-targets real-time ballistic recognition method based on movement multiple feature correlation[2] has been introduced in this paper. In the three-dimensional coordinate system constructed by three or more optical devices, the target point in the measurement frame belonging to the same target trajectory in space was identified and the connection between them was established. In the multi-objective spatial 3D coordinates, the noise introduced by the second order difference has well suppressed, which improves the adaptability and reliability of multi-target real-time trajectory identification and provides technical support for multi-target test and multi-trajectory measurement.

2. Multi-target real-time trajectory recognition method

2.1. Multi-target real-time trajectory recognition algorithm model

The multi-target real-time trajectory recognition algorithm model is based on target trajectory smoothing. Thus, the target trajectory is continuous and there is no sudden change in direction, velocity or acceleration, especially when the frame frequency of optical equipment is high. According to the continuity of the target trajectory, the evaluation function to judge the target correlation is selected. The selection principle is that the closer the motion speed is, the closer the motion direction is, and the closer the motion acceleration is, the smaller the value is. The multi-target real-time trajectory recognition algorithm model based on multi-target motion features is as follows:

$$\Psi = \omega_1\left(1-\frac{P_{i,k-1}P_{i,k}\cdot P_{i,k}P_{i,k+1}}{\|P_{i,k-1}P_{i,k}\|\cdot\|P_{i,k}P_{i,k+1}\|}\right)+\omega_2\left(1-\frac{2\left(\|P_{i,k-1}P_{i,k}\|\cdot\|P_{i,k}P_{i,k+1}\|\right)^{1/2}}{\|P_{i,k-1}P_{i,k}\|+\|P_{i,k}P_{i,k+1}\|}\right)+\omega_3\left(1-\frac{2\left(\Delta\|P_{i,k-1}P_{i,k}\|\cdot\Delta\|P_{i,k}P_{i,k+1}\|\right)^{1/2}}{\Delta\|P_{i,k-1}P_{i,k}\|+\Delta\|P_{i,k}P_{i,k+1}\|}\right) \quad (1)$$

In it: $P_{i,k-1}P_{i,k}=（X_{i,k}-X_{i,k-1},Y_{i,k}-Y_{i,k-1},Z_{i,k}-Z_{i,k-1}）$

$P_{i,k}P_{i,k+1}=（X_{i,k+1}-X_{i,k}, Y_{i,k+1}-Y_{i,k}, Z_{i,k+1}-Z_{i,k}）$

$\|P_{i,k-1}P_{i,k}\|=[(X_{i,k}-X_{i,k-1})^2+(Y_{i,k}-Y_{i,k-1})^2+(Z_{i,k}-Z_{i,k-1})^2]^{1/2}$

$\|P_{i,k}P_{i,k+1}\|=[(X_{i,k+1}-X_{i,k})^2+(Y_{i,k+1}-Y_{i,k})^2+(Z_{i,k+1}-Z_{i,k})^2]^{1/2}$

$\Delta\|P_{i,k\text{-}1}P_{i,k}\|=\|P_{i,k\text{-}1}P_{i,k}\|-\|P_{i,k-2}P_{i,k-1}\|$

$\Delta\|P_{i,k}P_{i,k+1}\|=\|P_{i,k}P_{i,k+1}\|-\|P_{i,k\text{-}1}P_{i,k}\|$

Ψ ——the objective correlation evaluation function；

w_1, w_2, w_3 ——the weighted factors of target motion direction, velocity and acceleration change, and $w_1+w_2+w_3=1$， $i=1,2...m$， $k=1,2...n$.

In the function, the three terms respectively represent the change of target motion direction, velocity and acceleration. The smaller the change, the smaller the value is. It can be seen that the motion direction, velocity and acceleration of the target point on the same trajectory are the closest, with the minimum change and the minimum value of the correlation evaluation function.

2.2. Target trajectory extrapolation interpolation

When the multi-target measurement data is lost due to objective reasons such as noise interference and target occlusion, the target ballistic discontinuity may occur. In order not to cause the same target trajectory to be divided into multiple target trajectories and the result of the intersection is not correct, the least squares fitting and extrapolation interpolation formula[4] are used to supplement the missing target point space coordinates. Considering that the target motion trajectory is generally a straight line, a quadratic parabola, a cubic curve, etc., the multi-objective real-time ballistic extrapolation interpolation model is a linear, quadratic, cubic fitting and extrapolation interpolation formula. Thus, the multi-target real-time ballistic extrapolation interpolation model is:

$$u(t_i)=a_0+a_1t_i+a_2t_i^2+...+a_nt_i^n \quad （2）$$

In it,
$$\begin{pmatrix} a_0\\ a_1\\ a_2\\ ..\\ a_n \end{pmatrix} = \begin{pmatrix} n+1 & \sum_{i=0}^{n}t_i & \sum_{i=0}^{n}t_i^2 & .. & \sum_{i=0}^{n}t_i^n\\ \sum_{i=0}^{n}t_i & \sum_{i=0}^{n}t_i^2 & \sum_{i=0}^{n}t_i^3 & .. & \sum_{i=0}^{n}t_i^{n+1}\\ \sum_{i=0}^{n}t_i^2 & \sum_{i=0}^{n}t_i^3 & \sum_{i=0}^{n}t_i^4 & .. & \sum_{i=0}^{n}t_i^{n+2}\\ .. & .. & .. & & ..\\ \sum_{i=0}^{n}t_i^n & \sum_{i=0}^{n}t_i^{n+1} & \sum_{i=0}^{n}t_i^{n+2} & .. & \sum_{i=0}^{n}t^{2n} \end{pmatrix}^{-1} \begin{pmatrix} \sum_{i=0}^{n}u_i(t_i)\\ \sum_{i=0}^{n}t_iu_i(t_i)\\ \sum_{i=0}^{n}t_i^2u_i(t_i)\\ ..\\ \sum_{i=0}^{n}t_i^nu_i(t_i) \end{pmatrix}$$

$u(t_i)=X(t_i),Y(t_i),Z(t_i)$;

$X(t_i),Y(t_i),Z(t_i)$ ——Spatial three-dimensional coordinates of the target moving in the launch coordinates, and usually n takes 1, 2 and 3.

2.3. Multi-target ballistic smoothing filter

The target ballistic smoothing filter model is usually established by five-point quadratic and three-time fitting, to correct the ballistic curve jitter caused by the correlation error and improve the target ballistic processing accuracy. The models are as follows respectively:

$$\begin{cases} \bar{u}_1 = \frac{1}{35}\left(31u_{i1} + 9u_{i2} - 3u_{i3} - 5u_{i4} + 3u_{i5}\right) \\ \bar{u}_2 = \frac{1}{35}\left(9u_{i1} + 13u_{i2} + 12u_{i3} + 6u_{i4} - u_{i5}\right) \\ \bar{u}_{ij} = \frac{1}{35}\left(-3u_{ij-2} + 12u_{ij-1} + 17u_{ij} + 12u_{ij+1} - 3u_{ij+2}\right) \qquad j = 3,4,\ldots n-2 \\ \bar{u}_{in-1} = \frac{1}{35}\left(-5u_{in-4} + 6u_{in-3} + 12u_{in-2} + 13u_{in-1} + 9u_{in}\right) \\ \bar{u}_{in} = \frac{1}{35}\left(3u_{in-4} - 5u_{in-3} - 3u_{in-2} + 9u_{in-1} + 31u_{in}\right) \end{cases} \tag{3}$$

$$\begin{cases} \bar{u}_1 = \frac{1}{70}\left(69u_{i1} + 4u_{i2} - 6u_{i3} + 4u_{i4} - 3u_{i5}\right) \\ \bar{u}_2 = \frac{1}{35}\left(2u_{i1} + 27u_{i2} + 12u_{i3} - 8u_{i4} + 2u_{i5}\right) \\ \bar{u}_{ij} = \frac{1}{35}\left(-3u_{ij-2} + 12u_{ij-1} + 17u_{ij} + 12u_{ij+1} - 3u_{ij+2}\right) \qquad j = 3,4,\ldots n-2 \\ \bar{u}_{in-1} = \frac{1}{35}\left(2u_{in-4} - 8u_{in-3} + 12u_{in-2} + 27u_{in-1} + 2u_{in}\right) \\ \bar{u}_{in} = \frac{1}{70}\left(-u_{in-4} + 4u_{in-3} - 6u_{in-2} + 4u_{in-1} + 691u_{in}\right) \end{cases} \tag{4}$$

In it, $\bar{u}_{ij} = \bar{X}_{ij}, \bar{Y}_{ij}, \bar{Z}_{ij}$,

$\bar{X}_{ij}, \bar{Y}_{ij}, \bar{Z}_{ij}$ ——Spatial 3D coordinate smoothing value of the target moving in the launch coordinates, $i = 1, 2..m$ and $j = 1, 2..n$.

2.4. Multi-target ballistic search

For the multi-target ballistic search[5], the priority matrix method was used in this paper. The basic idea is to not only consider the correspondence between a target point and a trajectory separately, but also to consider the correspondence between all target points and all known target trajectories as a whole. That means the sum of all corresponding function values Ψ is the smallest.

Let the elements of the matrix M to be the evaluation function values of the known target trajectory of the front k measurement frame and the respective target points on the $k+1$ measurement frame to be identified. The minimum element is determined on each line of the M matrix, that is, the target point of the measurement frame corresponding to the minimum value of each target ballistic evaluation function is determined. Then calculate the priority matrix B whose element $b_{i,j}$ is the sum of the other elements of the row and column of the M matrix element $m_{i,j}$. Finally, row i and line j are removed from the matrix M, and continue to search the smallest one in M and the biggest on in B, until all the target points on the measurement frame are discriminated.

$$b_{i,j} = \sum_{k=1,k\neq j} m_{i,k} + \sum_{k=1,k\neq i} m_{k,j} \tag{5}$$

3. Multi-target real-time ballistic recognition implementation strategy

According to multi-target real-time ballistic recognition algorithm model the above, the strategy algorithm flow can be obtained as follows:

Step 1: Multi-objective ballistic initialization modeling.

Initialization is the ballistic recognition of the first 3 frames and 5 frames of measurement data. By equation(1), a combination of the smallest Ψ value is found, and so on, the m target points in the first three or five frames of the measurement data are identified.

Step 2: Multi-trajectory interpolation and smoothing processing.

For each trajectory of multiple targets identified by Step1, interpolation is performed by equation(2) and smoothing is performed by using equation(3) and equation(4).

Step 3: Multiple target trajectory search processing.

On the basis of recognizing the trajectory of the k frame, the priority matrix method is used to quickly identify the trajectory of the $k+1$ frame.

Step 4: Multi-ballistic loop recognition.

Repeat the above steps until all the multi-ballistics have been identified.

The multi-target real-time ballistic recognition strategy algorithm process is shown in Figure 1.

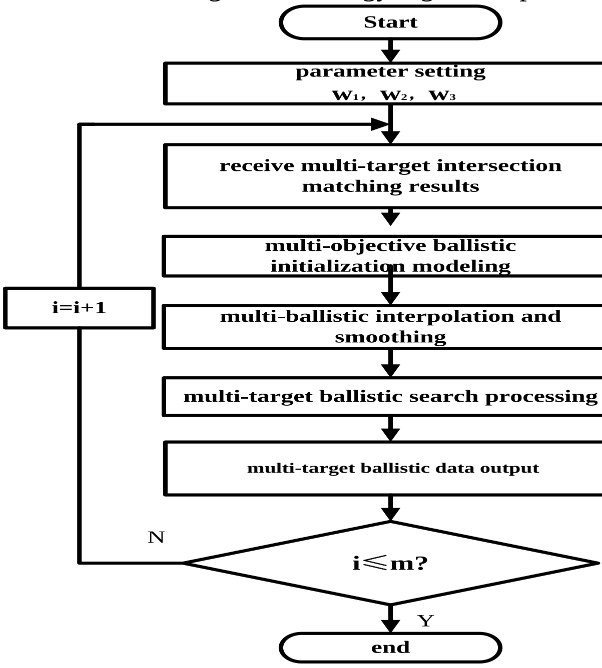

Figure 1. Multi-target real-time ballistic recognition strategy algorithm process

4. Experimental verification

4.1. Simulated 35-shot continuous multi-target simulation trajectory data

Thirty-five bursts of multi-target ballistic data were simulated by using VC6.0 software. The target ballistics of the simulation data are continuous, as shown in Figure 2. Multi-target ballistic separation was performed using parameters of ω1=0.8, ω2=0.2, and ω3=0.1, and the trajectory recognition result was 35 pieces, as shown in Figure 3. Since the simulated multi-target ballistic smoothness is better, the recognition rate is up to 100%.

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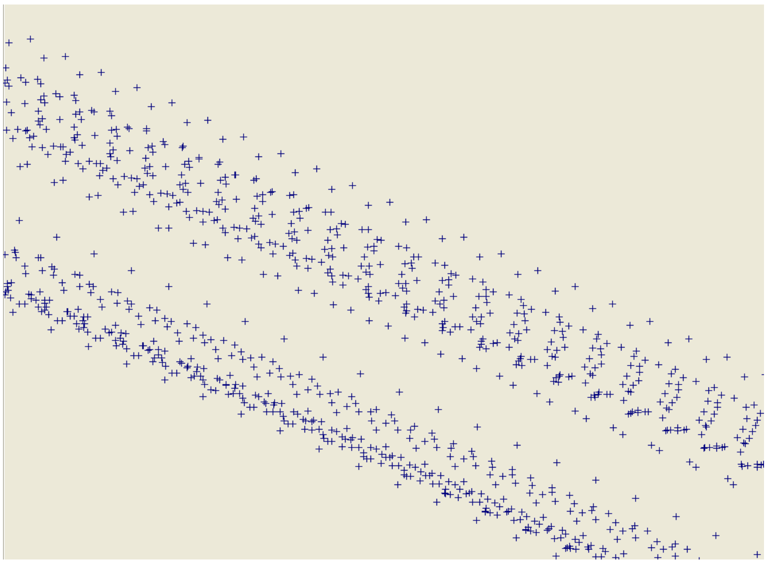

Figure 2. Multi-target 35 burst trajectory simulation data

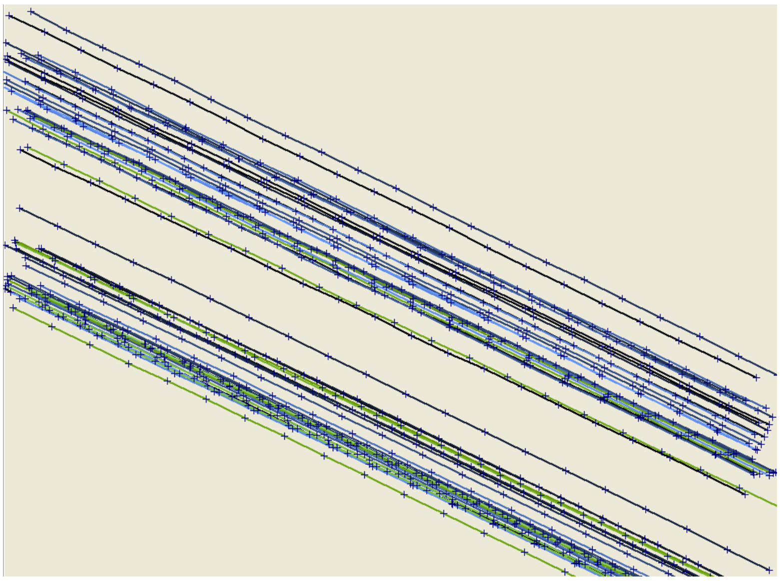

Figure 3. Multi-target 35 burst trajectory recognition result

4.2. Real - time trajectory identification of 4 salvo signals

Using the infrared theodolite to measure the 4 rounds of signal flares to obtain the measured ballistic data, and using parameters of ω1=0.75, ω2=0.15, and ω3=0.1 to make Real-time ballistic recognition. The results are shown in Figure 4. For the multi-target ballistic crossing and the loss point of the signal bomb 4, the multi-target real-time ballistic recognition is accurate and reliable.

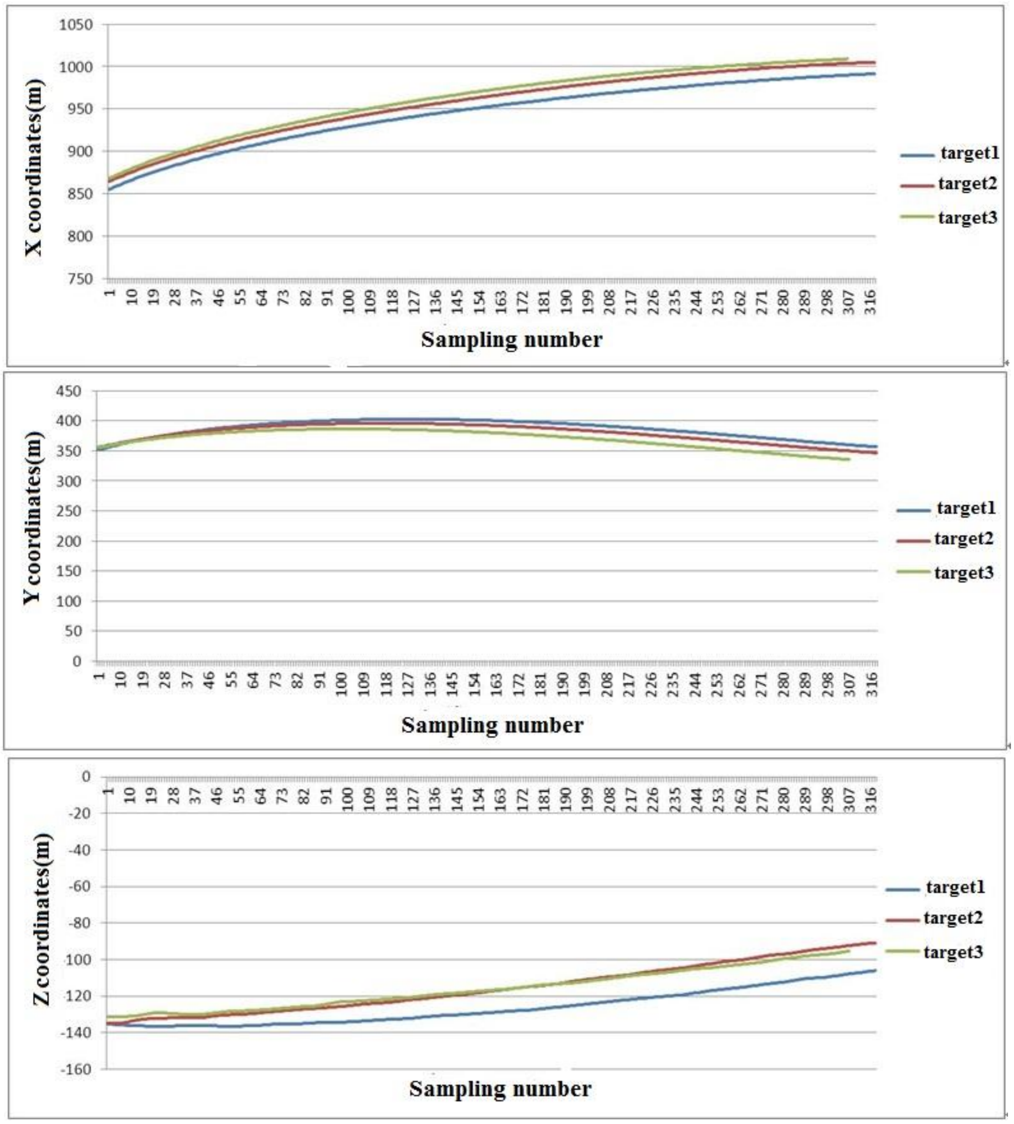

Figure 4. Real - time trajectory identification results of 4 salvo signals

5. Conclusion

In order to solve the problem of poor real-time and reliability of multi-target ballistic recognition caused by improper selection of ballistic recognition variables and less consideration of target motion characteristics in the continuous volley multi-objective optical ballistic measurement of rockets, missiles, and submunitions, a multi-objective real-time ballistic recognition method based on multi-feature correlation of motion is proposed. By establishing relevant mathematical model algorithms and implementation strategies, it provides theoretical guidance for optical measurement multi-target real-time ballistic recognition processing. The experimental results show that the proposed method can effectively improve the adaptability, real-time and reliability of multi-target real-time ballistic recognition, and provide technical support for real-time processing of multi-objective optical measurements.

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