Shadow Image Characteristics and Feature Extraction Method of Large Caliber Projectile in Outfield

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Abstract. According to the shape characteristics of large-caliber projectiles in shadow photography and the characteristics of external field environment, this paper focuses on the characteristics of external field shadow imaging and proposes a method for extracting the features of outfield shadow image of large-caliber projectiles. Based on the image preprocessing, the Bullet Tip feature points are determined by the intersection of the central axis and the edge, while the bullet tail feature extraction method based on ellipse fitting. The fitting accuracy of ellipse fitting method and upper and lower endpoint method are simulated and compared. The results show that the ellipse fitting method determining the center of the target end surface is better, with the extraction accuracy of 0.44 pixel.

1. Introduction

The shadow photography method uses orthogonal photography to capture the shadow contour image of moving projectile, and to achieve the purpose of measuring the flying attitude angle of the projectile by establishing the relationship between the images coordinates of the feature points and the spatial coordinates [1-4]. In this process, the camera captures the shadow contour formed by the opaque projectile irradiated by laser, which cannot express the details of the projectile surface. And then, how to determine the feature points in the shadow image based on the structure information of the projectile itself becomes the focus of the shadow target measurement image processors.

Yang zongwei [5] et al. extracted the shadow contour of the projectile based on wavelet denoising and canny edge detection, and adopted the azimuth constraint frame to identify the central axis of the projectile. Consequently, the two points of the bullet tip and the tail are approximated by the two endpoints of the main axis of the azimuth frame. However, in the case of a large target size, the parallax of the orthogonal shadow camera is large. It may occur that the intersection point of the target central axis and the projectile tail contour in the images of the two cameras is not the same feature point. As a
result, the line between the feature point of the image corresponding to the two cameras and the light source point is a line of different plane in space, and the calculation error is large.

Hui bingwei [6], zhao ju [7] et al., in the obtained orthogonal images of projectiles, adopt the "three-point method" to determine the attitude solving parameters, that is, the midpoint of the upper endpoint and the lower endpoint of the projectile is taken as the tail point, and the projectile tip point is taken as another characteristic point of the projectile, so as to determine the flight attitude of the projectile. However, due to the small rounded corners of the projectile end face, the curvature of the contour changes gently, and there are burrs, noise and other factors in the edge of the projectile, which leads to the characteristics of the upper and lower points of the projectile in the image is not obvious. Other than that, this method often requires manual pickup, and the extraction error is large.

The purpose of this paper is to analyze the shadow imaging characteristics of large caliber projectiles in outfield environment, and to propose a method to determine the tail center point of large caliber projectile based on ellipse fitting to solve the above problems.

2. Shadow Image Characteristics of Outfield Projectile

![Gray-scale distribution sampling line position diagram](image)

![Horizontal distribution of warhead gray scale](image)

![Vertical distribution of warhead gray scale](image)

![Horizontal distribution of cross-ring noise gray scale](image)

![Vertical distribution of cross-ring noise gray scale](image)

**Figure 1.** Grayscale curve of the projectile shadow image
3. Feature Extraction Method of Shadow Image Projectile

3.1. Feature Selection and Analysis of Large Caliber Projectile Image

The tip of a rotationally stabilized projectile is formed by a circular arc as a bus around the central axis [8], and its parallax is small in the measurement imaging process of orthogonal shadow. Thus, the intersection point between the central axis of the projectile and the contour of the projectile can be used...
as the feature point of the projectile tip. For the case where the projectile end face is projected as a straight line, the intersection point of the central axis and the projectile contour can be regarded as the projectile tail point; while when the projection edge of the end surface of the projectile tail is an ellipse, the center point of the ellipse can be regarded as the projectile tail point. It is easy to analyze the feature points by using the intersection of the central axis and the projectile contour. Therefore, the following analysis focuses on the feature extraction method of projectile tail based on ellipse fitting.

### 3.2. Equations Bullet Tail Feature Extraction from Shadow Image

The two vector point multiplication equations of the elliptic curve can be expressed as

\[ f(\vec{d}, \vec{z}) = \vec{d} \cdot \vec{z} = Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0 \tag{1} \]

Where is the ellipse parameter vector \( \vec{d} = [A, B, C, D, E, F] \), \( \vec{z} = [x^2, xy, y^2, x, y, 1] \) in (1). The edges of the processed image are serrated and stepped, and the coordinates of edge pixels are all integer values, which will lead to errors in fitting input data. In order to ensure the high accuracy of fitting curve, a restriction condition \( 4AC - B^2 = 1 \) is added in the fitting process, i.e. \( d^T L_0 \vec{d} = 1 \), where square matrix \( L \) is

\[
L = \begin{bmatrix}
0 & 0 & 2 & 0 & 0 & 0 \\
0 & -1 & 2 & 0 & 0 & 0 \\
2 & 0 & 2 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0
\end{bmatrix}
\]

The pixel coordinate \((x_i, y_i)\) at the end of the projectile tail are substituted into the elliptic equation. However, the ellipse to be fitted in the shadow image is not a perfect elliptic curve, \( f(\vec{d}, \vec{z}) \neq 0 \). In order to represent the fitting parameter error, the value of \( f(\vec{d}, \vec{z}) \) is taken as the distance between the pixel point and the curve represented by the fitting parameter. Consequently, the objective function can be established as follows

\[ F(\vec{d}) = \left| \sum_{i=1}^{n} f(\vec{d}, \vec{z}_i) \right|_{\text{min}} \tag{2} \]

Combined with the qualification conditions, the objective function solution is simplified to

\[
\begin{align*}
F^T F \vec{d} &= \lambda L \vec{d} \\
d^T L_0 \vec{d} &= 1
\end{align*} \tag{3}
\]

Where \( F \) is the matrix of all unknown numerical values of the pixel coordinates to be fitted, \( F = [\vec{z}_1, \vec{z}_2, \ldots, \vec{z}_n] \). The objective function has multiple numerical values of the pixel coordinates to be fitted. When the eigenvalue is a positive real number, the fitting error is the smallest, with the corresponding elliptic curve parameter vector \( \vec{d} = [A, B, C, D, E, F] \), and the elliptical geometric center is:

\[
\begin{align*}
X_c &= \frac{BE - 2CD}{4AC - B^2} \\
Y_c &= \frac{BD - 2AE}{4AC - B^2}
\end{align*} \tag{4}
\]
4. Simulation experiment results and analysis

In order to verify the accuracy of the extraction of the tail point based on the ellipse fitting, in this paper, the comparison and verification between ellipse fitting method and two-point method for determining the tail point method is carried out, where two-point method is based on the upper and lower ends of the projectile tail.

Firstly, the projectile simulation model is constructed with three-dimensional software, which is a symmetrical cylinder with small fillets at the boundary of both ends. The pitch angle of the model is set at 5 degrees, and the yaw angle is changed at 30 degrees. In a total of 5 ideal images by Parallel projection with projectile yaw angles of 15°, 30°...75°.

As shown in Fig. 3, In the case of different yaw angles, the results of the model end point extraction determined by the ellipse fitting are obtained. In addition, TABLE I. shows the calculation results of in-plane elevation angle and the accuracy of the end center extraction obtained by two extraction methods.

![Figure 3. Projectile Shadow Simulation Results](image)

(a) Shadow image with yaw angle of 15° (b) Shadow image with yaw angle of 45° (c) Shadow image with yaw angle of 75°

| Model attitude | Extraction method (°) | Error (°) | center point extraction error (pixel) |
|----------------|-----------------------|-----------|--------------------------------------|
| **Pitch** | ellipse fitting | two-point | ellipse fitting | two-point | ellipse fitting | two-point |
| 5 | 15 | 5.025 | 4.959 | 0.025 | -0.041 | 0.38 | 0.61 |
| 5 | 30 | 4.969 | 4.951 | -0.031 | -0.048 | 0.41 | 0.64 |
| 5 | 45 | 4.959 | 4.946 | 0.041 | -0.054 | 0.44 | 0.58 |
| 5 | 60 | 4.952 | 5.088 | -0.048 | 0.088 | 0.36 | 0.66 |
| 5 | 75 | 5.101 | 5.153 | 0.101 | 0.153 | 0.39 | 0.59 |

From Table 1, it can be seen that the method based on ellipse fitting is superior to the method based on two-point, and the accuracy of extracting the center of projectile tail can reach 0.44 pixel.

5. Conclusion

This paper focuses on the shadow image of large-caliber projectiles in the external field, which has the characteristics of low contrast, severe speckle noise and obvious shock wave. On the basis of image preprocessing, a tip extraction method based on the intersection of the central axis and the edge is adopted to determine the tip point of the projectile, while the feature point of the projectile is based on the ellipse fitting method. At last, the simulation results show that the extraction accuracy of the method based on ellipse fitting is 0.44 pixel, compared with the method based on the upper and lower points of the projectile tail.

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