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Research about Measurement Error of Bullet Head Traces Based on Improved Search Retreat Method

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Abstract: In order to compare accurately, this article first made a detailed analysis of the influencing factors and the measured data about traces of bullet head, and improved search retreat France which was in one-dimensional search interval in the process of handling the measurement errors caused by the position and attitude. This study proposed improved search retreat method suitable for handling errors. Through the test of the simulation case by the improved search retreat method, this algorithm is better proved by comparing.

Key words: Measurement error, bullet head traces, improved search retreat method

INTRODUCTION

In police practice, there is needed to judge whether two warheads the same gun fired according to the traces of the warhead. In the traditional method, through the visual observation of the microscope, the two lines on the type of warhead traces are compared to see whether the line thickness distribution is consistent. Traditional approach has two weaknesses: First, the efficiency is very low, because many cases are the “paradoxical” and therefore, the comparison to multiple warheads (e.g., dozens, hundreds) is almost impossible; Second, warhead samples is not easy to preserve, prone to rust damage, etc.

Modern high-precision data acquisition devices create the conditions to automatic matching method. While in the automatic matching, the selected data is bullet scratch marks. The traces of the warhead are divided into four main ridge traces and four ridge sub-edges. Since bullet barrel is rotated only a small angle through the barrel, the scratches distribution is a slash shape (at an angle with the cylinder bus). Automatic matching process method is divided into two steps: First step, Three-dimensional data of 8 traces of warhead collected by optical equipment is saved for the eight files. Measurement is taken as a reference plane fixed to the measuring space on the device xoy plane rectangular coordinate system, length measuring steps of the x-axis and the y-axis direction are 2.75 microns, the measurement accuracy of the z-axis is 1 micron and the data unit is mm. Each data file has more than 40 million lines, each row has three columns. Each row of three data is corresponding to the spatial coordinates (x, y, z) of a point on the surface of bullet. The first column corresponds to the x coordinate,

second column corresponds to the y coordinate and third column corresponds to the z-coordinate. Datum plane is in the vicinity of bullet traces, warhead posture should be adjusted while measurement so that: (1) Bullet cylinder centerline as possible parallel to the reference plane; (2) Parallel to the axis as far as possible toward scratches. Warhead posture is adjusted by artificial regulation, so the above two parallel are not exactly parallel (Xu, 1998).

The second step, in order to confirm the launch warheads guns, there is needed appropriate methods to discriminate the degree of similarity between a warhead with a warhead sample through computer matching. This is very practical, but difficult to achieve high accuracy (Xiao, 2007). While three-dimensional marks warhead data is collected by the optical device, the position and posture of the warhead can be manually adjusted while posture is the posture of the warhead or the state space, usually in the rotation. It is difficult to make warhead measured in the same posture and the same position by manual adjustment, then measurement errors will be caused. There are usually translational errors of about 0.03 mm and 0.2 degrees rotation errors.

This study attempts to solve the following problem: How to deal with the measurement errors caused by the position and posture, in order to compare two warheads in the same location and the same posture. (This assumes bullet diameter 7.90 mm, length of about 12 mm).

PROBLEM ANALYSIS SYMBOLS AND DEFINITIONS

ϵ = Translational error caused by artificial mediate
 α = Angle error caused by artificial mediation
 d = Measuring step

- δ = Comparison the least squares error
 $\vec{0}$ = Zero vectors
 I = The Column vector of all 1
 r = The bottom radius of bullet cylinder is 3.95 mm;
 l = The length of bullet is 12 mm

MODELING AND SOLVING

For the translational error of about 0.03mm caused by manual adjustment, we will can decompose it into three directions translational error of x, y, z; for the rotation error of 0.2° caused by manual adjustment, we will divided it into the rotation error of 0.2° about the warheads cylinder around the central axis and the rotation errors about the bullet cylinder wound in the head end (Han, 2007). These errors will be made following analysis:

Translational error handling

Translational error of X-axis direction: For XOZ plane (Fig. 1), with the left image as the reference image, when ε generates the X-axis direction error, along the X axis steps observed $d = 2.75$ microns. For bullet imaging has a relative displacement only in the X-axis, there is need to move the bullet imaging a distance of close to ε along the X-axis offsets in the opposite direction, then the impact of errors will be reduced (Wang, 2003). So that, the position and posture compared with the two warheads will be improved. (If the shift is in the negative direction, the reference image will be converted).

Translational error of Y-axis direction: For XOZ plane (Fig. 2), with the left image as the reference image, when ε generates the Y-axis direction error, the bullet imaging has a relative displacement only in the Y-axis, there is need to move the bullet imaging a distance of close to ε along the Y-axis offsets in the opposite direction, then the impact of errors will be reduced. So that, the position and posture compared with the two warheads will be improved. (If the shift is in the negative direction, the reference image will be converted).

Translational error of Z-axis direction: For XOZ plane (Fig. 3), with the left image as the reference image, when ε generates the Z-axis direction error, the bullet imaging has a relative displacement only in the Z-axis, there is need to move the bullet imaging a distance of close to ε along the Z-axis offsets in the opposite direction, then the impact of errors will be reduced (Zhou *et al.*, 2010). So that, the position and posture compared with the two warheads will be improved. (If the shift is in the negative direction, the reference image will be converted).

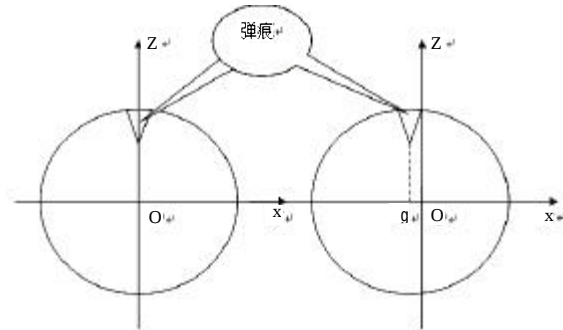


Fig. 1: Simplified diagram of translational error about X-axis direction

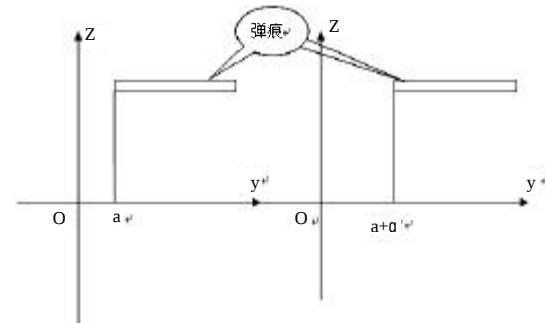


Fig. 2: Simplified diagram of translational error about Y-axis direction

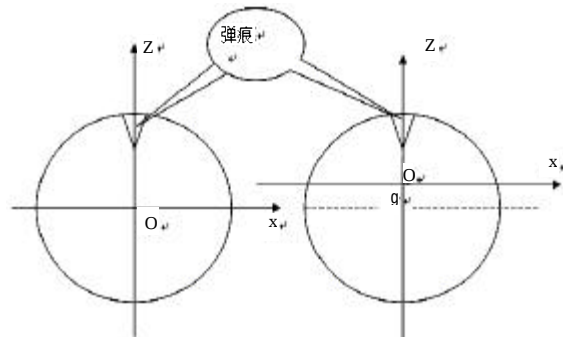


Fig. 3: Simplified diagram of translational error about Z-axis direction

Translation error handling: The handling principle of three types of error above is similar, so we will gives only the processing method of the Y-direction shifts, similarly the other direction. There is a method called retreat method (Xie *et al.*, 2003) in search interval, the basic idea is that from one point, according to a certain step, try to determine the three adjacent points that the function value presented “Low-low-high”. If one direction is unsuccessful, then return to the opposite direction for

search. Following this idea, we will put forward improved search retreat method appropriate for the problem. The basic idea is to determine the need for error handling at first. If necessary for processing, we will take a surface image of a warhead as a reference (the image intercepted to the initial position of the Y-axis), Intercept images required matching same and calculate the least squares error δ_0 . Then we will make the image compared move a step distance of a length of d along Y-axis direction, Intercept Images again, compare the reference image and calculate Least-squares error δ_1 . Through comparing δ_0 and δ_1 , we will determine the direction and length of the pan while also taking into account the range of values of step length can not exceed the maximum limits of translation error (Jiang, 1992).

The steps of improved search retreat method about translation error of Y-axis.

Set up the number of the value of x in a section as x_{count} , X_1 , Y_1 , $Z_1(X_1, Y_1)$ and X_2 , Y_2 , $Z_2(X_2, Y_2)$ are both column vectors of $x_{count} \times 1$ which are the data vectors (function) in three coordinate directions respectively from two warheads (to A and B edge) of two edges (Liu, 2005).

$$X_1 = X_2 = ((i-1)d)_{x_{count} \times 1} \quad I = (1)_{x_{count} \times 1}$$

Step 1: Determine the presence of the direction translation

Order:

$$Y_1^{(0)} = Y_2^{(0)} = \vec{0}.$$

Calculate the least squares error:

$$\delta_0 = (Z_1(X_1, Y_1^{(0)}) - Z_2(X_2, Y_2^{(0)}))^T (Z_1(X_1, Y_1^{(0)}) - Z_2(X_2, Y_2^{(0)}))$$

Order:

$$Y_1^{(0)} = \vec{0}, Y_2^{(1)} = dI$$

Calculate:

$$\delta_A = (Z_1(X_1, Y_1^{(0)}) - Z_2(X_2, Y_2^{(0)}))^T (Z_1(X_1, Y_1^{(0)}) - Z_2(X_2, Y_2^{(0)}))$$

Order:

$$Y_1^{(1)} = dI, Y_2^{(0)} = \vec{0}$$

Calculate:

$$\delta_B = (Z_1(X_1, Y_1^{(1)}) - Z_2(X_2, Y_2^{(0)}))^T (Z_1(X_1, Y_1^{(1)}) - Z_2(X_2, Y_2^{(0)}))$$

If $\delta_0 < \delta_A$ and $\delta_0 < \delta_B$, this two edges have the best effect in the original coordinate system compared, without treatment; Otherwise, for an edge as a reference, another one edge will needed to do translation adjustments. Might, let the A image of the entire image has a certain offset of the Y positive direction than B (in the opposite direction may be similarly considered), so that $\delta_1 < \delta_A$, turn to Step 2.

Step 2: Temptation: Order:

$$Y_2^{(k+1)} = (k+1)dI$$

Calculate:

$$\delta_{k+1} = (Z_1(X_1, Y_1^{(0)}) - Z_2(X_2, Y_2^{(k+1)}))^T (Z_1(X_1, Y_1^{(0)}) - Z_2(X_2, Y_2^{(k+1)}))$$

Step 3: Comparison error: If $\delta_{k+1} \leq \delta_k$, turn to Step 4; otherwise, stop temptation, output k

Step 4: Continue to test: So, $\delta_k: \delta_{k+1}, k: k+1$, if $K \leq k_{max}$ ($k_{max}d$ is as the maximum range set by exploration), turn to Step2; Otherwise, stop temptation output k (Yang and Huang, 2008)

At this point, the data curve of the B edges will be translation the length of kd along the negative direction of Y and optimal results compared will be achieved.

Rotation error handling

r around the central axis of the cylindrical: For XOZ plane (Fig. 4), when the rotation error of α° about the cylinder around the central axis is generated, the image forming of bullet is obtained from the original image rotation around the origin of" and has an impact on the x , z . Let the original coordinates x_1 , z_1 , the offset coordinates x_2 , z_2 . There is the following relationship exists:

$$\begin{cases} \frac{z_2}{z_1} = \cos \alpha \\ \frac{x_2 - x_1}{z_1} = \sin \alpha \end{cases} \quad (1)$$

Rotation error in XOY plane with the center of bullet head end:

For XOY plane (Fig. 5), when the rotation error of α° in XOY plane with the center of bullet head end is generated, the angle has an impact on both x and y . Let the original coordinates x_1 , y_1 , the offset coordinates x_2 , y_2 . There is the following relationship exists:

$$\begin{cases} \frac{x_2 - x_1}{l} = \cos \alpha \\ \frac{l - (y_2 - y_1)}{l} = \sin \alpha \end{cases} \quad (2)$$

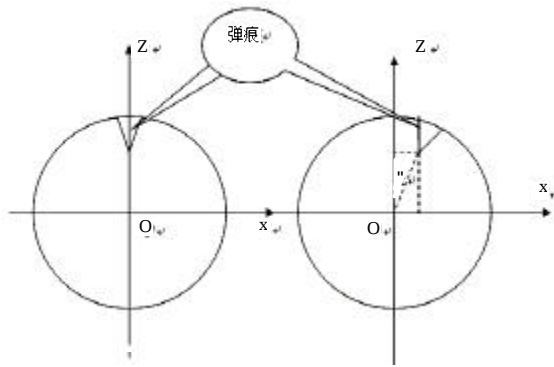


Fig. 4: Simplified diagram of the rotation error around the central axis of the cylindrical

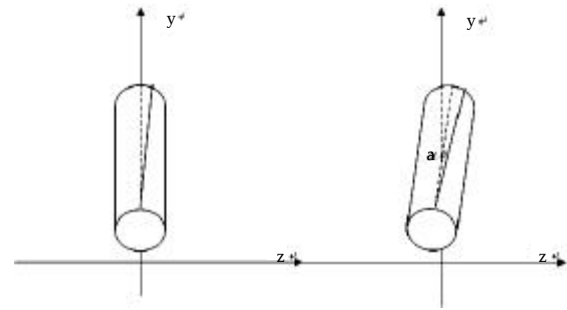


Fig. 6: Simplified diagram of the rotation error in YOZ plane with the center of bullet head end

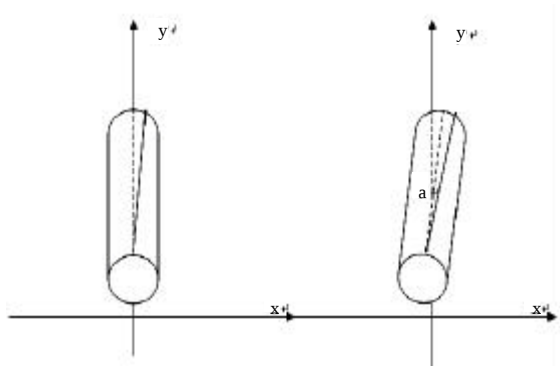


Fig. 5: Simplified diagram of the rotation error in XOY plane with the center of bullet head end

Rotation error in YOZ plane with the center of bullet head end: For YOZ plane (Fig. 6), when the rotation error of α° in YOZ plane with the center of bullet head end is generated, the angle has an impact on both x and y. Let the original coordinates y_1, z_1 , the offset coordinates y_2, z_2 . There is the following relationship exists:

$$\begin{cases} \frac{1 - (y_2 - y_1)}{1} = \cos \alpha \\ \frac{z_2 - z_1}{1} = \sin \alpha \end{cases} \quad (3)$$

Rotation error handling: The handling principle of three types of error above is similar, so we will give only the processing method of the rotation error around the central axis of the cylindrical, similarly the other direction.

We will improve the above search retreat method and find the suitable treatment. By adjusting the X-axis direction displacement, we will calculate the adjustment of the angle and calculate the adjustment rotation of the Z-axis direction, then calculate the least square error, to find the most suitable position in the allowable range.

The steps of improved search retreat method about the rotation error around the central axis of the cylindrical.

Set up the number of the value of Y in a section as y_{count} , $X_1, Y_1, Z_1(X_1, Y_1)$ and $X_2, Y_2, Z_2(X_2, Y_2)$ are both column vectors of $y_{count \times 1}$, which are the data vectors (function) in three coordinate directions respectively from two warheads (to A and B edge) of two edges.

$$Y_1 = Y_2 = ((i-1)d)_{y_{count \times 1}}, I = (1)_{y_{count \times 1}}$$

Step 1: Determine the presence of the rotation translation

Order:

$$X_1^{(0)} = X_2^{(0)} = \vec{0}$$

Calculate the least squares error:

$$\delta_0 = (Z_1(X_1^{(0)}, Y_1) - Z_2(X_2^{(0)}, Y_2))^T (Z_1(X_1^{(0)}, Y_1) - Z_2(X_2^{(0)}, Y_2))$$

Order:

$$X_1^{(0)} = \vec{0}, X_2^{(0)} = dI, \sin \beta_1 = \frac{d}{r}$$

Calculate:

$$\delta_A = \left(Z_1(X_1^{(0)}, Y_1) - \frac{Z_2(X_2^{(0)}, Y_2)}{\cos \beta_1} \right)^T \left(Z_1(X_1^{(0)}, Y_1) - \frac{Z_2(X_2^{(0)}, Y_2)}{\cos \beta_1} \right)$$

Order:

$$X_1^{(0)} = dI, X_2^{(0)} = \vec{0}$$

Calculate:

$$\delta_B = \left(\frac{Z_1(X_1^{(0)}, Y_1)}{\cos \beta_1} - Z_2(X_2^{(0)}, Y_2) \right)^T \left(\frac{Z_1(X_1^{(0)}, Y_1)}{\cos \beta_1} - Z_2(X_2^{(0)}, Y_2) \right)$$

If $\delta_0 < \delta_A$ and $\delta_0 < \delta_B$, this two edges have the best effect in the original coordinate system compared, without treatment (Zhang *et al.*, 2011); Otherwise, for an edge as a reference, another one edge will needed to do translation adjustments. Might, let the A image of the entire image has a certain offset of the Y positive direction than B (in the opposite direction may be similarly considered), so that $\delta_1 < \delta_{A_0}$ turn to Step 2.

Step 2: Temptation: Order:

$$X_2^{(k+1)} = (k+1)dI, \sin \beta_{k+1} = \frac{(k+1)d}{r}$$

Calculate $\cos \beta_{k+1}$ and:

$$\delta_{k+1} = \left(Z_1(X_1^{(0)}, Y_1) - \frac{Z_2(X_2^{(k+1)}, Y_2)}{\cos \beta_{k+1}} \right)^T \left(Z_1(X_1^{(0)}, Y_1) - \frac{Z_2(X_2^{(k+1)}, Y_2)}{\cos \beta_{k+1}} \right)$$

Step 3: Comparison error: If $\delta_{k+1} \leq \delta_k$, turn to Step 4; otherwise, stop temptation, output β_k

Step 4: Continue to test: So, $\delta_k = \delta_{k+1}$, $k = k+1$, if $k \leq k_{\max}$ ($k_{\max}$ d is as the maximum range set by exploration), turn to Step 2; otherwise, stop temptation output β_k

The output of β_k means the angle counterclockwise rotation at the origin as center while the data curve of the B edges adjust. At this point the result of comparison is best.

SIMULATION EXAMPLE

There are the three-dimensional data of 8 traces of warhead collected by optical equipment. Parts of the data are in Fig. 7. Measurement is taken as a reference plane fixed to the measuring space on the device xoy plane rectangular coordinate system, length measuring steps of the x-axis and the y-axis direction are 2.75 microns, the measurement accuracy of the z-axis is 1 micron and the data unit is mm (Zheng *et al.*, 2007).

The data are processed by improved search retreat method as in Fig. 8 and the following results are.

To make the match effect to be the best, the translation errors should be processed as that the data curve of the B edges will be translation the length of

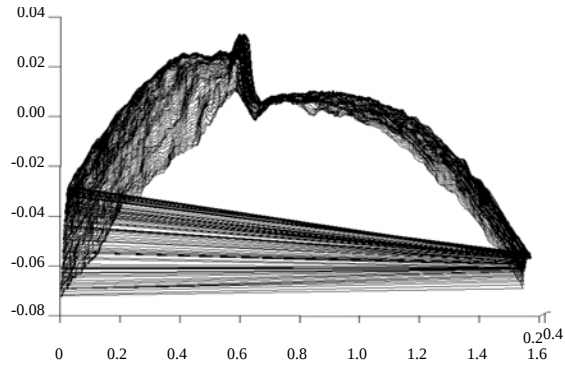


Fig. 7: graph of original data

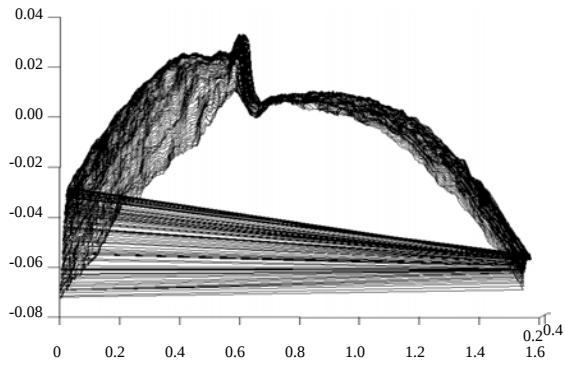


Fig. 8: graph of the data by error processed

0.027 mm along the negative direction of X, 0.021 mm along the negative direction of X and 0.018 mm along the negative direction of Z.

For the rotation error while the data curve of the B edges adjusts, the angle counterclockwise rotation at the origin as center is 0.183° , the rotation angle in XOY plane with the center of bullet head end is 0.09° and the rotation angle in YOZ plane with the center of bullet head end is 0.204° .

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