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Research on the Artillery Shell Motion Parameters Automatic Detection Technology Based on Image Processing

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Abstract

To realize automatic test of the shell motion parameters in the artillery experiment, the digital high-speed camera is used to gather the shell motion images. By applying digital image processing technique the characteristic images of shell are extracted accurately. Combined with the measuring principle of the shell motion parameters, a image test system is designed and realized automatic test of the shell motion parameters. The test results of shell motion images indicated that, the image extraction algorithm presented in this paper is easy to use and universal, and the precision of data measurement is increased. At present, the image test system has been applied in the data analysis in the artillery experiment and obtained good performance.

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Keywords: Shell motion parameters; Image processing; Artillery experiment

1. Introduction

Artillery shell motion parameters that need to be measured in artillery experiments include attack flight angle, the instant stick speed when the shell hits the target and so on. Primary means of measuring is high-speed photography. To achieve automatic recognition of high speed photographic images and automatic recognition the motion parameters, digital image processing technology is used to feature and detect extractions from shell moving images. A shell motion parameters automatic detection system is designed. Among them, artillery attack angle image detection method is based on the center axis method [1,2]. Firstly, through extracting the shell center axis from the images of two cameras collected at the same time, the yaw angle and pitch angle of attack can be measured by constructing real center axis equation in three-dimensional space. Secondly, regard shell as a particle, bomb-shaped recovery method is used to detect shell outline border which can detect shell centroid position on the image

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furthermore. Then the instantaneous stick speed can be measured by single pixel program labeling. Bomb-shaped recovery method is another important part of the image detection. In this paper, the shell center axis extraction in artillery shell motion images and bomb-shaped recovery method are described, the instantaneous stick speed is detected based on image processing technology, moreover, compares with the results of the instantaneous speed detection method based on the net-target[3,4].

2. Shell motion image feature extraction

2.1. *Shell flying motion image*

Some representative shell flight motion images captured by high-speed digital camera as shown in Fig.1.(a) ,Fig.1.(b)and Fig.1. (c). From these images, we can see that shell has different warhead shape and images full of complex background noise, especially shell outline information in images is half-baked.

Fig.1.(a) Cone-shaped warhead motion image ; Fig.1.(b)Square-shaped warhead image ; Fig.1.(c) Image with complex background noise

2.2. *Image extraction algorithm of the shell axis*

In this paper, the shell center axis extraction process as shown in Fig.2.

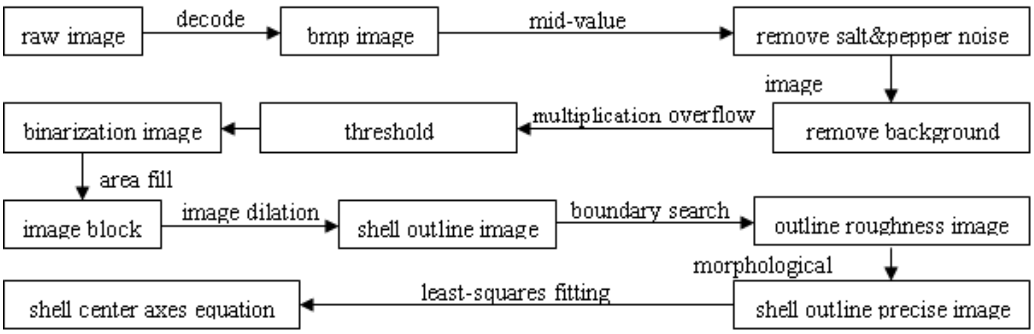

Fig.2. The extraction flow of shell center axis

Image processing is mainly to solve the following problems. Firstly, eliminates the image background noise by binary segmentation, extracts shells contour feature image. Secondly, locates the boundary of shell outline.

2.2.1. Image denoising preprocessing

Image denoising process is set into two steps. Firstly, using airspace median filter smoothing the whole image, make rough noise cancellation treatment to eliminate local salt and pepper noise. Secondly, according to the moving image detection theory, uses the frame subtraction for removing a large area of the scene background noise as meticulous noise cancellation treatment[5,6]. Each of the test background image that doesn't contain shell information is set as G1, and the images containing shell motion information sequences are set as G2i (i=1…N). A new sequences of images G3i (=1…N) are defined as using G2i subtracting G1 which contains shell information with most background noise are removed. Practice shows that after the frame subtraction operation, background plate, brick wall and scene of background noise are basically removed. Shell contour feature information is clearly.

2.2.2. Image two values segmentation algorithm

Image two values segmentation [7] operation can separate shell information and background information from the whole image.

Fig.3. The shell image after two value segmentation

In this paper, the image multiplication overflow algorithm is used to achieve automatic image analysis and process function. The first step is multiples sequences of images G3i (=1…N) by 10. Because of the brightness of shell is significantly greater than the brightness of the background, after the execution of the multiplication, shell image area will become brighter because gray stretch while the background will become more black. In the worse, the image multiplication operation may cause the shell image highlighted area gray value greater than 255 which makes effluence. Therefore, the next step is take image two values segmentation treatment by setting the overflow value to 255, and no overflow values are set to 0. The result of the two values segmentation is show in Fig.4, it can be obverse that the separation is satisfactory, and the two-value images are defined as G4i (i=1…N).

2.2.3. The shell center axis extraction algorithm

The axis equation can be derived by the upper and lower edge straight lines of the shell indirectly. Firstly, locate the positions of shell body upper and lower edge straight lines. Define the image length right direction as X-axis, the image height upward direction as Y-axis, the image lower left corner as the origin O. Scan each of the sub-graph in Fig.3 from top to bottom, and bottom to top with point-by-pixel. Store each row and each column of the first white point pixel corresponding to a one-dimensional array called top array and bottom array respectively.

Image process will inevitably lead to shell boundary line brook. So these two arrays contain both shell boundary information and useless information. In this paper, the morphological filtering method is used to accurately extract the shell top and bottom boundary. The morphological filtering method is based on the morphological characteristics of the goal itself as a transcendental knowledge of signal filtering technology. Shell usually has the following form: axis- symmetrical, parallel plane lines between top and bottom boundary, the left boundary of the shell body is projected to a straight line, the warhead is conical or square and so on. Firstly, Top Array and Bottom Array are used to locate the top and bottom boundary projected straight lines l1and l2.

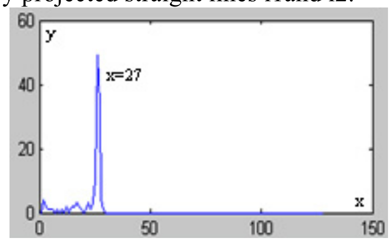

Fig.4. Statistic histogram of SubArray

Take sub-graph in Fig.3 for example, due to the shell top and bottom boundary line are parallel, any of a vertical line passing through the shell image, and the distance between the intersections should be constant. Therefore, the data can be detected by Top Array and Bottom Array corresponding to row pixels position difference signal Sub Array. Theoretically Sub Array values distributed as follows, when on behalf of shell body information it is a constant, when on behalf of conical warhead values it is decrease with the conical warhead linearly, when on behalf of shell boundary information it is a defect random value. Sub Array characterization category can be discriminated by histogram the boundary pixels difference signal. Take differential signal value and the number of difference signal as abscissa and ordinate respectively. Add up the same data appears frequency F in Sub Array. Take sub-graph in Fig.3 for example, its histogram shown as Fig.4.The peak value abscissa is 27, which proves that the signal difference of 27 data is the most. The other difference signal statistical values appearing probabilities are low. Though the shell body is long, and top and bottom boundary line are parallel, the histogram peak represents the shell information. Redefine the on behalf of shell top and bottom boundary real information array as TempTArray and TempBArray respectively. The data which satisfy the condition (abs (Top Array-Bottom Array) =27) in Top Array and Bottom Array are endowed to TempTArray and TempBArray. The 'abs' means absolute value. TempTArray and TempBArray are applied for least squares and obtained l1 and l2 whose top and bottom boundary of envelope image coincides very well. Even in very small shell image can be accurately detected in shell body boundary straight line. Therefore, the accuracy of the extraction of shell center axis is very high. The entire image extraction process is fully automated by computer. The center axis extraction results of each sub-graph in Fig.3 are shown in Fig.5.

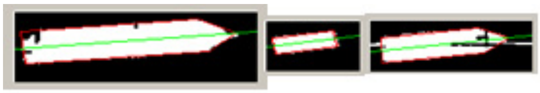

Fig.5. Image extraction result of shell center axis

3. Shell centroid extraction and hitting target real-time speed measurement

3.1. *Principle of centroid method measuring of shell instantaneous speed*

This paper describes the application of image processing to extract the shell centric position, and measure the target time of the centroid crossing two identification lines to obtain instant speed bump. To improve the accuracy of the identification line, two straight lines with a single pixel width are defined as the identification line in the application, the corresponding distance of the identification lines are calibrated through a camera, and by measuring the time of shell centroid crossing the two program identification lines on the measurement image and the distance of the two identification lines can derive the instantaneous speed of shell. The principle of measuring shell instantaneous speed is shown in Fig 6, the centric of shell is defined as P and the two identification lines are defined as l1 and l2 respectively in program. The actual trajectory distance calibrated by the camera between l1 and l2 is defined as d. The time of shells centroid crossing l1 and l2 is t=|t1-t2|.So V is the instantaneous speed of the ratio d and t. Due to limited space, this article does not describe the camera calibration process.

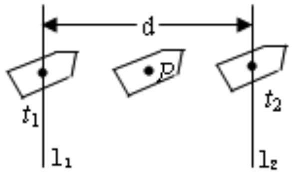

Fig.6. The principle of measuring shell instantaneous speed

3.2. *Shell shape recovery method*

After two-value segmentation operation, the shell outline image has the characteristic of boundary faults and defects which may cause totally wrong results when calculated the shell centric position by using the two-value image directly. To accurately extract the shell centric position of the image, the hell shape must be recovered first..

Considering difference kinds of warheads, shell recovery is mainly to solve the following three problems, automatically detects the type of warhead, shell body shape recovery and warhead shape recovery.

Reference[8] uses the linear CCD measured data to recovery shell shape. This paper mainly discusses the restoration techniques base on the image plane of the shell shape. As shown in Fig.3, the shell outline two-value image is obtained after a series of image process, and it is observed that the shell border exists broken and convex hull phenomenon. Define the right and upward direction of the image as x-axis and y-axis positive respectively, the Cartesian coordinate system as Fig.7. The straight line l1 separates shell body and head into two parts. Then, the shell shape recovery includes shell body recovery and shell heard recovery respectively. Furthermore, the shell body recovery includes the top boundary recovery, the bottom boundary recovery, and the left boundary recovery. The accurately upper boundary and lower boundary are extracted at the shell center axis detection step. It should also recovery the left boundary of the body, the turning position between the warheads and shell body, and the warhead vertex (c point).

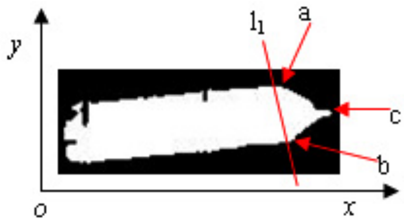

Fig.7. Coordinate system and feature points

For the detection of shell body left boundary, considering any shell left boundary is vertical with upper and lower boundary, during the image processing, all elements of the left boundary line are scanned, and which are used to construct multiple lines. The line closest to the top and bottom boundary includes maximum number of elements of left edge is selected as left boundary line of shell. Similarly, scan all elements of the shell head position in two-value image. The position of point c can be detected by Harris corner detection method[9]. By fitting a straight line between point a and c, point c and b respectively, the warheads boundary can be recovery.

3.3. *Coordinate calculation method of shell centroid*

The shell contour area after the recovery is defined as R, f(i, j) stands for pixel gray of the i-th row j-th column in the area. Then centroid coordinate of the shell could be calculated as follows:

$$\bar{i} = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} i \times f(i,j)}{\sum_{i=1}^{M}\sum_{j=1}^{N} f(i,j)} \tag{1}$$

$$\bar{j} = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} j \times f(i,j)}{\sum_{i=1}^{M}\sum_{j=1}^{N} f(i,j)} \tag{2}$$

For a binary image, f (i, j) is equal to 1.Therefore, to calculate the centric of shell, it is necessary to find out the points which are belong to the interior N or boundary points of the shell. The shell is a convex polygon, and there are three methods of identification its interior points: ray method, arc-length method, and interior angles sum method. This paper ray method is selected. According the parity of the number of vertical rays' intersection between a test point and shell polygon that can be determined whether the point belong to the shell polygon area. Assuming P(x, y) is the pixel of test point, the recovery shell polygon contour base on ray method is shown in fig.8. In the coordinate system of image, draws a ray from the test point P in the direction of y=-∞, and counts the number of intersection N between the vertical rays and shell polygon. If N is odd, then point P is belong to the polygon, otherwise, the point P would fall into outside the polygon area. If the ray passes through the vertices of the polygon, the principle called "left-open right-off" is used to judge whether the test point is belong to the polygon. When the ray crosses to a peak of shell polygon, if the edge is on the left of the ray, the intersections should be counted. Otherwise, the intersections would be ignored. The shell centroids calculated by ray method is shown as "+" in fig.9 and observes that all of the centroids are located in the central axis. The high accuracy of measurement results can lead to high accuracy of the hitting speed calculated by the centroid method.

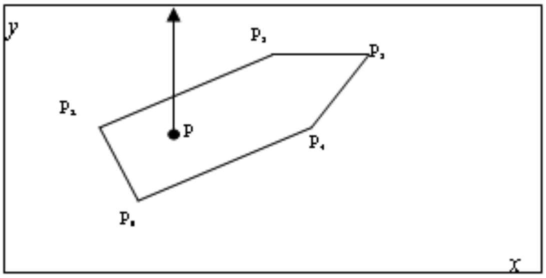

Fig.8. The diagram of pixels and shell outline polygon

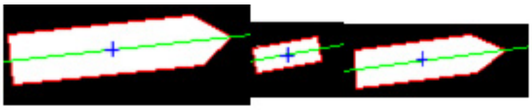

Fig.9. The shell shape restoration and centroid test result

4. Analysis of image detection accuracy

The above qualitative analysis shows that, extraction accuracy of artillery shell's axis dependes on the extraction accuracy of its upper boundary and lower boundary while the measurement accuracy of centroid method dependes on the recovery accuracy of shell shape.

The paper presents a criterion to assess extraction accuracy of upper and lower boundaries by comparing the practice distance d between upper boundary and lower boundary with calculate value d1 in image process. The detection accuracy can be calculated as

$$\delta = \frac{|d - d_1|}{d_1} \times 100\% \tag{3}$$

The imaging detection diameter, the actual shell diameter and detecting errors in each sub-graph of Fig.1 are presented in Table 1. It can be see that the error between the actual shell diameter and detection diameter was less than 5%. The experiment results of large number of images indicate that, there is no apparent mathematical distribution relationship between the above detecting errors and the actual shell diameter. However, it can be guaranteed that the errors smaller than 5%, including of the errors of camera calibration.

Tab.1 Actual dimension and imaging measurement result of shell diameter

Image	d（mm）	d1（mm）	δ（%）
Fig.1.(a)	82.17	84.5	2.76
Fig.1.(b)	28.78	30.0	4.07
Fig.1.(c)	147.56	150.0	1.62

To determine the accuracy of centroid method applied on detecting shell's instant speed, the paper makes a comparison between the centroid method and the net-target method of velocity measurement. Based on electrical measuring principle, two net-target shelves which are entwined with enameled wire are installed on ballistic trajectory, when the net-target shelf is broken by the moving shell, the TTL voltage level would reverse. By recording the interval time of the twice reverse can calculate the speed of shell. The compare of measurement results with net-target method, centric method and artificial discrimination in each sub-graph of Fig.1 are shown in table 2.Where v, v1 and v2 stand for the results of net-target method, centric method and artificial discrimination respectively.

Tab.2 The measurement result of shell instant speed

Image	v(m/s)	v1(m/s)	v2(m/s)
Fig.1.(a)	1050.54	1048.76	1046.48
Fig.1.(b)	515.26	514.96	514.12
Fig.1.(c)	1143.74	1142.98	1146.5

Table 2 shows that v is always larger than v1. The measurement results of centric method are always bigger the results of net-target method. That because the net-targets are installed in front of the high-speed camera system and near the artillery muzzle, addition with influenced of air resistance, the measurement speed with centric method is always slower than the measurement speed with net-target method. Moreover, It is the artificial subjective judgements that cause v2 is not equal to v, especially when the amplitude-frequency of camera sampling is relatively high, the error would become greater. In calculating the recovery of shell shape, the paper takes all the pixels of the shell's image into consideration. As the cumulative calculation will reduce the error effectively, it is proved that the centroid method applied on measuring the instantaneous speed of shell is feasible.

5. Summary

Based on digital image processing technology, the axis of moving shell is extracted effectively which provided the technical of automatic measuring the attack angle of artillery shell with computers. The paper also recovered the shape of shell accurately by extracting image features of shell, which makes it possible for centroid method to detect the instant speed of shell. A large number of test results shown that, the shell image processing method described in this paper could solve the problem of automatic identification of high-speed photography images for artillery test in a complex environment effectively. This method overcame the subjective error caused by manual discrimination. Moreover, the centroid method was regarded to be more suitable than the net-target method. Results of this research project has been widely used in the photometric tests in shooting ranges.

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