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A Method to Locate Firing Points by Fusing Double CCD and GIS

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Abstract

The precise positioning of the firing explosion point is an effective means to test the technical performance of artillery weapons and equipment warfare, but when the CCD single pole distance method is directly used to detect the explosion point, it is often affected by the obstacles in the shooting visual area, terrain and landform, and the detection and positioning accuracy is difficult to meet the evaluation requirements. To this end, the double CCD intersection method is first used to locate the explosive point, and the target recognition and positioning algorithm is used to realize the visual explosion point positioning, but this method also has the phenomenon of missing detection of the bomb point and ricochet explosion point. Then, the sensor is used to collect GIS signals at the point of explosion, which can well detect the location of missed bounces and ricochets, but there is also the cost of time registration and spatial coordinate system registration. In order to give full play to the complementary advantages of the two positioning methods, this paper proposes to establish a fusion localization model. Experiments have verified that the fusion positioning method improves the accuracy of the detection of the explosion point of traditional single live shooting, and can provide a reference for the positioning detection of related points of interest.

Keywords

CCD; GIS; Fusion Positioning; Precision.

1. Introduction

In the assessment of live fire, in order to improve the detection accuracy of explosive points, a variety of information acquisition system platforms are generally used. After digging deeper into the logic of the internal positioning relationship, it is found that they all complement each other well with various types of observation equipment, different measurement technology means, and different parameter performance. CCD as one of the commonly used measurement equipment, it has high accuracy of observation blowing point, stable performance of remote monitoring, high accuracy of target identification, simple visualization of operation, but the observation distance is constrained by the terrain environment and natural climate, and the 3D GIS positioning is influenced by small environmental factors. In the experimental verification, the use of double CCD can capture the information of the blast points, but for jumping bullets, missing bullets prone to false detection and omission, GIS using sensors to collect the signal of the blast points, but need time alignment and spatial coordinate system alignment transformation, and the process of collecting information is not able to be visualized. Therefore, this paper proposes to establish a method to locate the firing points based on the fusion of double CCD and GIS, and to realize the data fusion to locate the coordinates of the firing points by playing the advantages of both locating methods. Its overall positioning framework is shown in Figure 1.

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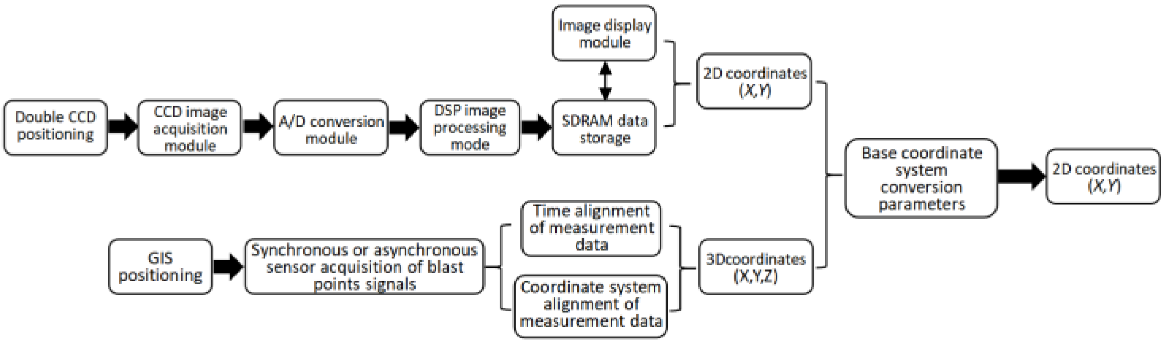

Figure 1. Fusion positioning framework diagram

2. CCD Position

2.1. Target Collection

CCD consists of an array of regularly arranged semiconductor MIS capacitors, the way to collect signals is mainly MIS capacitor storage and transfer charge current, its system components include optical systems, lenses, image processing modules, therefore, CCD cameras are also known as CCD charge-coupled devices. The use of double CCD front rendezvous method to collect the information of the blast points, its working principle is that the reflected light of the blast points into the optical system, was switched by the lens focus on the chip, according to the collection of the signal strength of the blast points generated by the corresponding charge regular discharge, output the composite video signal through filtering, amplification and present the blast points image. As shown in Figure 2.

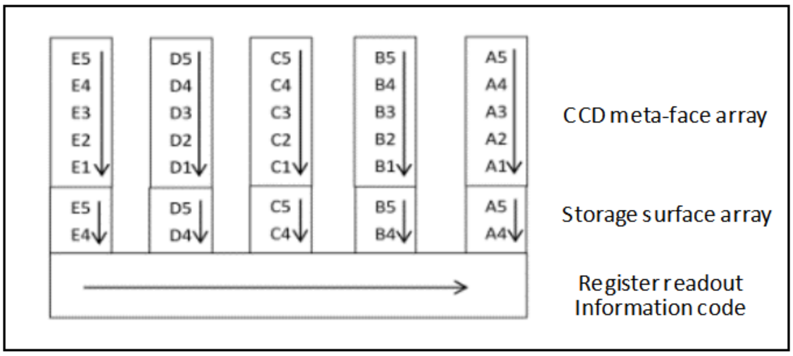

Figure 2. Principle of CCD acquisition information

2.2. Positioning Algorithm

In live firing, CCD collects the targets mainly by collecting and reconstructing the visible light signal in the center of the targets, and through the role of high-speed A/D conversion module, the center coordinates of the target image points are derived according to the algorithm. The algorithm is shown in equation 1.

$$X_0 = \frac{\sum X_i V_i}{\sum V_i}; Y_0 = \frac{\sum Y_i V_i}{\sum V_i} \quad (1)$$

Where X0 and Y0 denote the 2D coordinates of the target center point, Xi and Yi are the sequence numbers in i target image elements, and Vi is the signal strength and amplitude value corresponding to i target image elements.

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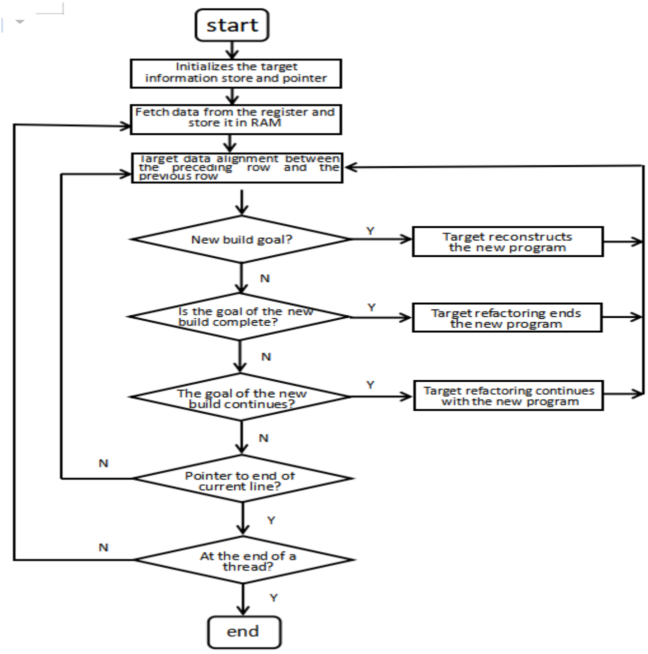

Figure 3. Flow chart of center coordinate algorithm

The center coordinate method is the principle of using calculus to find the center of the target in a 2D plane right-angle coordinate system. The algorithm is simple and suitable for double CCD to locate the coordinates of the blast points. It is shown in Figure 3.

3. GIS Position

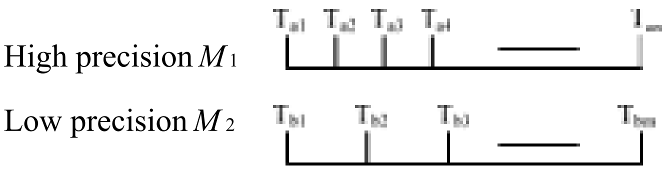

Figure 4. Time alignment error diagram (High precision M_1, Low precision M_2)

GIS is based on many sensors collecting signals from the blast points for positioning. And the signals collected by sensors [1] need to be aligned in time and space coordinates [2] to ensure that the measurement information is uniformly regularized to the same reference time and space coordinates. This is shown in Figure 4.

The alignment deviation [3] refers to the process of converting multi-sensor data with "zero error" [4] to ensure that the data from many sensors are fused in a unified time and space coordinate system, thus demonstrating the advantages of 3D GIS data fusion positioning, as shown in Figure 5.

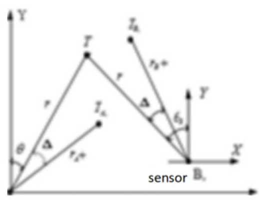

Figure 5. Schematic diagram of the measured value error of the sensor

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3.1. Time Alignment of Measurement Data

Time alignment [5] is to convert the information collected by multiple asynchronous sensors [6] into a uniform temporal coordinate system through an algorithm to ensure that the collected signals do not superimpose invalid signals, usually using sensors with long scanning times to unify the data information and ensure temporal integrity. In this paper, we learn to study the time alignment algorithm from three aspects: least squares, Interpolation and extrapolation method and maximum entropy inference machine [7].

3.1.1. Least Squares Method [8]

Regarding the study of time alignment consistency, scholars firstly used the least squares method to solve the problem for time coordinates. The least squares algorithm uses the minimum sum of squares of the residuals as the performance criterion to make fitted values of the sensor sub-measurements. The most fundamental solution idea is: if the ratio of the scanning signal period of multiple sensors is (set to an integer value), will receive the third class sensor sub-measurement space time virtual coordinate value [9] as the time third class sensor real valid value, the time third class sensor capture measurement value and the first class sensor measurement value for the target space state fitting value processing, repeatedly realize that the sensor many times temporally for virtual measurement fitted value fusion processing, realized sensor a, sensor b and n sensors to maintain the measurement value in time for effective information fusion, excluding the error factor of information fusion due to time deviation [10] when the sensor captures the signal.

3.1.2. Interpolation and Extrapolation Method [11]

In the specified same time range of the sensor acquisition data to take the interpolation and extrapolation method processing, aimed at time to multiple high-precision target measurement data to the corresponding multiple low-precision target data, to achieve different sensors to synchronize measurement and acquisition of information data.

The interpolation and extrapolation method can be performed according to the following procedure:

Selecting a time range to distinguish static and dynamic based on the information of moving targets and fixed simulated targets in the live fire area, and the time period can be selected as h-hour, s-minute and m-second level for state statistics;

Adopting the measurement accuracy from low too high to sort the data of information collected by different types of sensors in a surge [12] process;

In order to obtain measurement data with consistent time intervals, a descending order method is usually used to gradually project high precision measurement data to low precision to achieve interpolation and extrapolation at time points to ensure that asynchronous sensor measurement data are in the same time coordinate system at all times.

3.1.3. Time Alignment Method based on Maximum Entropy Inference Machine

Using the high-rate blast point information collected during direct fire of the artillery organization to form a cluster of energy-power density spectra of the projectile explosion signal [13], the low-velocity projectile explosion signal is estimated by the minimum mean square criterion to achieve superimposed information collection from different rate sensors on different low-power targets, and the information collected from different classes of sensors at different powers is temporally aligned, and the method is limited by the need to convert to geodetic before measurement 2000 coordinate system before the measurement can be used, in addition to the sensor transfer function and firing area target density and other factors need to be considered.

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3.2. Coordinate System Alignment of Measurement Data

After the time alignment of the measurement data, the spatial coordinate system alignment needs to be solved, and the spatial coordinate system alignment is mainly to complete the coordinate transformation of many sensors. The measurement data coordinate system transformation is essentially the transformation process of regularizing the information collected by the sensors at the explosion point of live fire area detection to the corresponding information in the same reference coordinate system. The 3D automatic observation platform designed in this paper pre-sets the sensor signal receiver, places multiple sensors on the unified detection platform, and selects the geodetic 2000 coordinate system as the reference coordinate system of the fusion positioning system, as shown in Figure 6.

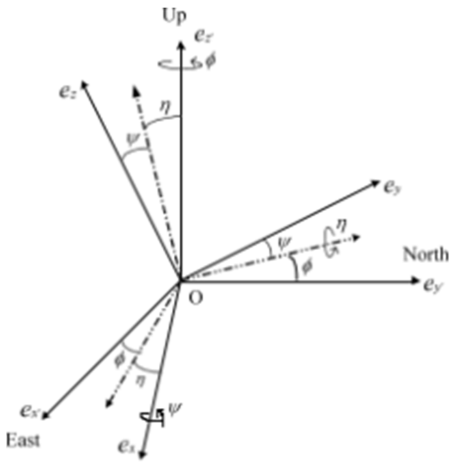

Figure 6. Time alignment transformation diagram

After the transformation of the coordinate system of the measurement data of multiple sensors, the spatial coordinate system deviation value alignment still has to be carried out. GIS mainly adopts the method of averaging the accumulated data of the blast points information for processing, and the average measurement values obtained are recorded into the information processing terminal.

4. Parameter Transformation of the Base Coordinate System

In view of the fact that Geodetic 2000 is usually used as the reference coordinate system in live firing, it is necessary to transform the 3D spatial coordinates of the blast point collected by GIS into the Geodetic 2000 coordinate model $(x0, y0)$. The transformation of the reference coordinate system should explore the scaling, shifting and twisting of the 2D spatial Cartesian coordinate system, and also take into account the changes of the 3D spatial ellipsoid parameters Bd and Bf, in order to make the 3D spatial coordinate system compatible with the Geodetic 2000 coordinate system. The theoretical basis for the transformation of the base coordinate system parameters is the Geodetic 2000 coordinate system calculus formula, and considering the issue of page length, the process of reasoning for the fusion positioning formula is described in the literature [14] [15] and is not described here.

5. Fusion Positioning

After completing the temporal and spatial alignment of the measurement data, the 3D GIS and double CCD are composed of fusion positioning mode to establish the 3D spatial coordinate model, as shown in Figure 7. In this model, the center of the CCD observation line axis is the

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coordinate origin, the X-axis is calibrated to coordinate north, and the Y-axis is perpendicular to the X-axis and forms a spatial coordinate system for information acquisition with the Z-axis.

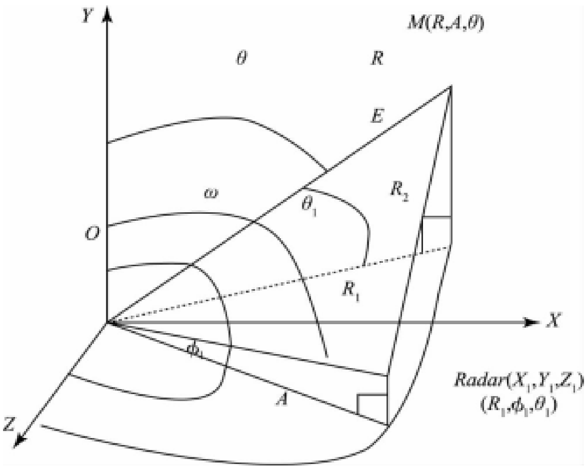

Figure 7. Logical relationship of fusion positioning model

The spatial coordinate system for information acquisition with the center of the double CCD observation line axis [16] as the origin, with azimuth, elevation and observation distance to calibrate the target coordinates, has the following mutual correspondence:

Assuming that the function variables such as = 90°- Eand $R_1, \theta_1, \varphi_1, R_2, A, E$ are specified in advance, the target position is determined according to the spatial coordinate system single station positioning method to find R (i.e., double CCD). The position relationship between double CCD and 3D GIS positioning is shown below.

$$\begin{aligned} &X = Rsin\theta sin\theta c Z = Rsin\theta sin\theta \\ &Y = Rcos\theta co_1 = R_1 sin\theta_1 cos\varphi_1 \\ &Z_1 = R_1 sin\theta_1 sin\varphi_1, Y_1 = R_1 cos\varphi_1 \\ &R_2^2 = (X - X_1)^2 + (Y - Y_1)^2 + (Y - Y^1)^2 \end{aligned} \tag{2}$$

The joint solution of the equation in equation 2 yields $R1$

$$R = R_1 P + Q \tag{3}$$

In this model, the 3D GIS position R1, θ1, Φ1 in 3D space [17] relative to the dual CCD can be determined accurately, so the error is negligible, and the impact of the angular error of 3D GIS positioning relative to the dual CCD on the positioning results is mainly considered. The partial differentiation of R2 , A , θ for R respectively:

$$\left.\begin{aligned} &\frac{\partial R}{\partial R_2} = \frac{1}{\sqrt{(R_1 / R_2)(P^3 - 1) + 1}} \\ &\frac{\partial R}{R\theta} = R_1 G / (R_1 P / Q + 1) \\ &\frac{\partial R}{\partial A} = -R_1 \sin\theta_1 \sin\theta \sin(-\varphi_1 + A)(R_1 P / Q + 1) \end{aligned}\right\} \tag{4}$$

According to the error space transfer function Eq. 5 is derived:

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$$\delta R = \sqrt{(\frac{\partial R}{\partial R_2}\delta_{R2})^2 + (\frac{\partial R}{\partial \theta}\delta_\theta)^2 + (\frac{\partial R}{\partial a}\delta_A)^2} \tag{5}$$

The results of the analysis in Eqs. 2 to 5 above show that

(1) The distance positioning error is comparable to the ranging error of the GIS itself;

(2) The distance measurement error decreases with the increase of the target distance;

(3) The double CCD acquisition image element error is negligible to the distance positioning error;

(4) The smaller the distance between the double CCD and the information acquisition instruments and sensors in the GIS positioning model, the smaller the measurement distance error;

(5) Using the double CCD separate acquisition target method, its calculation of target coordinates and accuracy formula is as follows:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} R_{\cos} E_{\cos} A \\ R_{\sin} E \\ R_{\cos} E_{\sin} A \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} \delta_x \\ \delta_y \\ \delta_z \end{bmatrix} \begin{bmatrix} \cos A \cos\theta - R \sin A \cos\theta - R \cos A \sin\theta \\ \sin\theta, 0, R_{\cos}\theta \\ \sin A \cos\theta, R \cos A \cos\theta - R \sin A \sin\theta \end{bmatrix} \begin{bmatrix} \delta_R \\ \delta_A \\ \delta_\theta \end{bmatrix} \tag{7}$$

In Eq. 5 and Eq. 6: δzy_x_is the coordinate accuracy R, A, θ of the calculated target; the combined value of slant distance and azimuth of the target [18]; $\delta\theta A_R$ is the range accuracy and angle accuracy.

With the above equation, the accuracy of the blast points measurement in the double CCD and GIS positioning model can be obtained [19].

6. Experimental Verification

As an example, the live firing test data of a contract tactical training base was used for the detection of the blast points using the double CCD rendezvous method alone [20], and then the GIS blast points were used for detection. Seen in Figures 8 and 9.

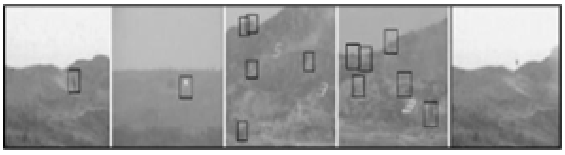

Figure 8. Results of double CCD detection of blast points

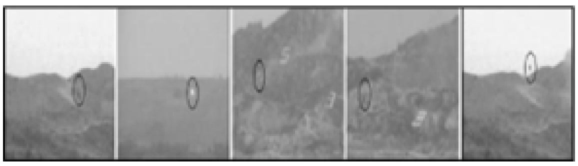

Figure 9. Results of GIS detection of blast points

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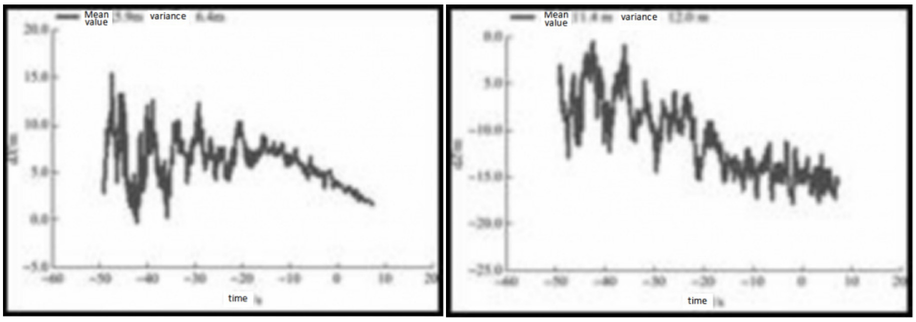

Figure 10. Plot of the primary difference of the fusion positioning coordinates (Dx, Dy)

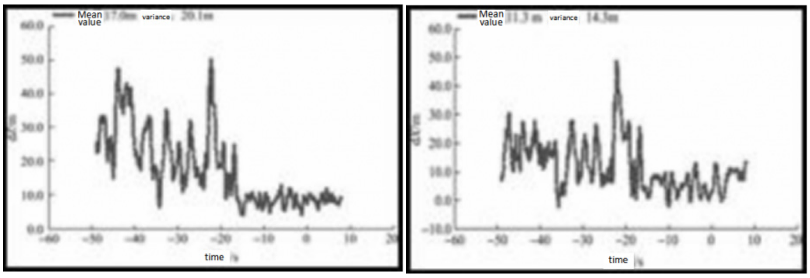

Figure 11. Quadratic difference curves of fusion positioning coordinates (Dx, Dy)

Table 1. Comparison results of fusion positioning detection blast points

Object number	Dual CCD and GIS fusion status calculation results				Total station measurement results (m)	Systematic deviation (m)
	Main side measurement distance (m)	Subjective azimuth (°)	Side view azimuth (°)	Calculation result (m)		
1	1449.15	41.5546	116.2963	X=88714.13 Y=38984.29	X=88714.86 Y=38984.78	ΔX=0.73 ΔY=0.49
2	2341.55	39.8536	127.3745	X=88288.19 Y-39135.36	X=88288.63 Y-39135.87	ΔX=0.44 ΔY-0.51
3	3148.36	39.6560	125.2972	X-88271.42 Y=39116.47	X-88271.96 Y=39116.26	ΔX-0.54 ΔY=0.21
4	4518.42	53.1957	112.6378	X-88137.35 Y=39537.11	X-88137.04 Y=39537.89	ΔX-0.31 ΔY=0.78

System acquisition target coordinate verification results: evaluation times 4 times, reaching the design 4 times, qualified rate = 100%

(1) From Figure 8 and Figure 9 blast points detection results can be seen that both systems detect the blast points, but from the perspective of detection accuracy and stability, GIS fusion positioning can accurately measure the coordinates of the ricochet blast point shown in the third picture in Figure 9.

(2) From the analysis of the two graphs in Figure 10 and Figure 11, the use of double CCD forward rendezvous information acquisition and GIS positioning to obtain the coordinates of the blast points are not very different, but from Table 1 fusion positioning detection of blast points comparison results, fusion positioning accuracy is higher, fusion positioning in missing

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bombs, jumping bombs and other special situations can be more advantageous disposal, the system complementary operation is more stable.

7. Conclusion

The use of double CCD rendezvous method to locate the blast points, using the target identification and positioning algorithm to achieve visualization of blast points positioning, but this method also has missed detection of missing bombs, jumping bombs detection ; and then the use of sensors to collect the GIS signal of the blast points, can be very good detection of missing bombs, jumping bombs positioning, but there is also the need for time alignment and spatial coordinate system alignment cost overhead. In order to develop the complementary advantages of the two localization methods, a fusion positioning model is proposed in this paper. After experimental verification, the fusion positioning method improves the accuracy of traditional single live-fire blast detection, and can provide a reference for relevant localization detection of interest.

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