Design of Calibration System for Motion Attitude Measurement of Large-caliber Projectile

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Abstract. To meet the large-caliber projectile motion measurement system calibration requirement, developed a large-caliber projectile motion measurement system calibration system, gives the calibration principle and working process, design a visibility good green light source as the collimating light source, the design targets based on the filtering and PSD field grid position detection module; Aiming at the calibration requirement that the six faces of cavity cross grids frame cannot be shielded, the cavity cross grids adjustment module is designed. Error analysis shows that the calibration error of the system is 0.062mm.

1. Introduction

The large-caliber projectile motion attitude measurement system has the advantages of non-contact measurement, high measurement accuracy, large measurement information capacity and easy storage, etc. It is widely used in the measurement of projectile motion position and attitude information. Compared with the indoor environment, the field experiment environment is relatively bad, with the existence of natural wind, environmental dust, uneven ground, stray light and other interference factors, which seriously affect the accuracy of measurement and calibration. The calibration system of the large-caliber projectile motion attitude measurement system can be used to calibrate the camera spatial pose of the shadow photography station, so that the two shadow cameras in the photography station have orthogonal optical axes, and the intersection point of optical axes is located in the center of the photographic field. Meanwhile, the transformation relationship between camera image coordinates and spatial coordinates is determined.

At present, the calibration system of ballistic target path can be divided into two structures: suspension type and carrier type [1]. Suspension type is mainly used in some measurement target paths of the US army, while research in China and European countries mainly focuses on carrier type. Nanjing University of science and technology has carried out in-depth research on carrier target channel calibration. In essence, it is based on the grid plane on the carrier, the optical axes of the two cameras in the calibration station are orthogonal, and the magnification ratio of the camera image plane at the grid plane is calibrated by using the geometric information of the grid plane. Sihai Rong [2], Wei long Xu [3], et al. used laser and photoelectric position sensors to accurately locate the spatial position of cross grids, improving the consistency of calibration posture of cross grids in different measuring stations.
Wei Song, et al [4]. Designed an integrated high-precision carrier, using a six-axis parallel robot as the spatial position adjustment mechanism of the carrier, and positioning the carrier axis with a single laser and a single PSD to improve the accuracy and efficiency of target channel calibration.

Therefore, according to the characteristics of existing shadow photography stations, this paper develops a calibration system for the motion attitude measurement system of large-caliber projectile, whose calibration precision can reach 0.062mm.

2. Composition and calibration principle of motion attitude measurement system for large calibre projectile

The principle of attitude measurement and calibration of large-caliber projectile motion is shown in Fig.1, which is mainly composed of collimating light source module, field character grid position and posture detection module, field character grid, hollow field character grid adjustment module and inter-station transfer module. The collimating light source module is composed of parallel light source, regulating mechanism and vibration isolation belt. Cross grids pose detection module is composed of filtering target, optical window, strip horizontal bubble and PSD. Hollow field word grid adjustment module is composed of rigid base, movable adjustment platform, six degrees of freedom platform, base and field word grid. The transfer module between stations is composed of wheeled mobile trolley and stacking truck.

![Figure 1. General schematic diagram of calibration system for projectile motion attitude measurement in outer field](image)

During calibration, first install the parallel light source on the manual adjustment table, adjust the height of the tripod so that the parallel light source beam can be emitted horizontally and coincide with the trajectory line; The field grid is located in the CCD camera field of the shadow photography station, and the height of the movable adjustment platform is adjusted so that the laser beam falls within the receiving range of the PSD measuring surface. The filter target is set up at a certain distance from the field grid, so that the center of the filter target coincides with the beam center of the reference light source, and the transmitted beam shines on the PSD measuring surface. Adjust the axis of the grid to coincide with the laser beam. Adjust the level of the top surface of the grid. Based on the cross grids of the calibration attitude, adjust the spatial posture of the shadow camera, so that the optical axis of the camera and the line between cross grids and the center of the grid surface coincide, take the shadow image of cross grids, and carry out the calibration.

3. Analysis of experiment

3.1. Collimating light source design

In order to improve the visibility of reference light source and facilitate the debugging of field calibration experiment, green light is selected as the reference light source in the calibration system of large-caliber projectile motion attitude measurement. Since semiconductor laser has the advantages of small volume, light weight and high reliability [5], semiconductor laser is selected as the reference light source in this paper. The object is shown in Fig.2. Its wavelength is 520 nm, the beam divergence Angle is better than 0.03 mrad, and the diameter of the central main spot within 200 meters is \( \leq 10 \text{ mm} \).
3.2. Design of grid pose detection module of field word

When the spot receiving device is far away from the parallel light source, the actual laser spot size on the surface of the receiving device will be much larger than the design size of geometric optics, and there are multi-stage diffraction rings around the central spot, which is beyond the measurement range of PSD. Therefore, the effect of the laser beam diffraction ring on the measurement needs to be filtered out. In order to improve the alignment accuracy of the filtering target and the axis of the reference light source, the filtering target as shown in Fig. 3 is designed. In the center is a round hole smaller than the PSD measurement area. The front and back sides are engraved with the scale line with the center of the circular hole as the center of the circle, the width of which is 0.1mm, and the resolution of the filtering target is 1mm.

(a) Line carving diagram  (b) Real picture of filtering target

**Figure 3.** Filtering targets

PSD has the advantages of small size, light weight, high resolution and high response speed [6], which can realize the continuous measurement of spot location, therefore. In this system, two-dimensional PSD is selected as the spot location detection device, and the performance indicators are shown in Table 1.

| Serial number | The performance parameters | The parameter value                      |
|---------------|----------------------------|------------------------------------------|
| 1             | Measuring surface size     | 12 × 12 mm                               |
| 2             | encapsulation              | ceramic                                  |
| 3             | Wavelength range           | 320–1060 nm                               |
| 4             | Accuracy of measurement    | Φ5 mm area: 25 μm                         |
|               |                            | Φ10 mm area: 87 μm                        |

**Table 1.** Performance indexes of S1880 2d PSD

3.3. Cavity cross grids design of adjustment module

Before the taira grid reaches the calibration posture, the spatial position of cross grids needs to be constantly adjusted. Therefore, the resolution and accuracy of the adjustment mechanism will directly affect the accuracy and efficiency of the spatial position adjustment of cross grids. The six-axis parallel robot has the advantages of high precision, compact structure, high stiffness and large bearing capacity, etc. [7]. Therefore, the six-axis parallel robot is selected as the fine-adjusting mechanism of spatial position of the cross grids. In order not to cover the grid surface of the cross grids, a six-axis parallel robot with a large visible area is selected as the fine-tuning mechanism of the cross grids, and its performance parameters are shown in Table 2.
Table 2. Main performance parameters of the six-axis parallel robot under the condition of field of view non-interference

| Serial number | Parameter                                | The numerical |
|---------------|------------------------------------------|---------------|
| 1             | Angular rotation resolution              | ≤0.01°        |
| 2             | Angular repeat positioning accuracy      | ≤0.03°        |
| 3             | Angular positioning accuracy             | ≤0.04°        |
| 4             | Displacement motion resolution           | ≤0.005 mm     |
| 5             | Displacement repeated positioning accuracy| ≤0.01 mm      |
| 6             | Displacement positioning accuracy        | ≤0.04 mm      |

The calibration scene of the camera station is shown in Fig. 4, from which it can be seen that the equipment in the calibration process mainly includes laser parallel tube, shadow camera, pulse laser, cross grids, movable adjusting table, six-axis parallel robot, rigid base, PSD, etc.

4. Calibration accuracy analysis
The error distribution of single-station calibration is shown in Table 3.

| Serial number | Error sources                                                                 | The error value (μm) |
|---------------|-------------------------------------------------------------------------------|---------------------|
| 1             | The coincidence error between the optical axis of laser and the central axis  | 52.36               |
|               | of field grid                                                                |                     |
| 2             | The alignment error between the camera's optical axis and the center line of  | 27.96               |
|               | the grid surface before and after the cross grids                            |                     |
| 3             | Vertical error between reflection screen and camera optical axis              | 17.20               |

Assuming that the above errors are independent of each other, then the coordinate calibration errors of single station feature points are obtained
\[ \delta = \sqrt{\delta_1^2 + \delta_2^2 + \delta_3^2} = 0.062 \text{mm} \] (1)

5. Conclusion

According to the characteristics of the existing shadow photography station, a calibration system of the motion attitude measurement system of large caliber projectile is presented, and its calibration principle and working process are introduced. The green light source with good visibility is selected as the collimating light source, and the grid position and posture detection module based on filtering target and PSD is designed. Aiming at the calibration requirement that the six faces of Cavity cross grids frame cannot be shielded, the hollow character grid adjustment module is designed. Error analysis shows that the calibration error of the measurement system is 0.062mm.

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