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Improvement Detecting Method of Optical Axes Parallelism of Shipboard Photoelectrical Theodolite Based on Image Processing

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Abstract

An improvement detecting method was proposed according to the disadvantages of testing method of optical axes parallelism of shipboard photoelectrical theodolite (short for theodolite) based on image processing. Pointolite replaced 0.2″ collimator to reduce the errors of crosshair images processing and improve the quality of image. What's more, the high quality images could help to optimize the image processing method and the testing accuracy. The errors between the trial results interpreted by software and the results tested in dock were less than 10″, which indicated the improve method had some actual application values.

Keywords

Improvement Detecting Method, Shipboard Photoelectrical Theodolite, Optical Axes Parallelism, Image Processing

1. Introduction

The optical axes parallelism is one of the vital indexes to evaluate the measurement precision of theodolite [1]. As the azimuth-zero set constant reference for the tracking & control equipment, theodolite is a main calibration tool when the ship in dock.

A testing method of optical axes parallelism of shipboard photoelectrical theodolite was proposed in reference [2], which provided a new way under dynamic conditions. While the detection accuracy and efficiency of the method were limited by hardware and software in some way, it was necessary to apply an improvement detecting method to overcome those limitations.

2. Error Analysis of Image Processing

In the former image processing method progress, CCDs were used to record the images or videos of the crosshair of 0.2″ collimator, and then the data stored in CCDs would be acquired by DAQ (Data Acquisition) cards and sent to computer, and the results would be calculated immediately. The whole progress was shown in **Figure 1**.

During the detecting processing, many factors such as hardware, experimental environment and the image processing calculation may affect the final result. According the analysis of factors mentioned above, some conclusion could come to as follows.

1) According to the imaging principle, the crosshair getting smaller when the axes of 0.2″ collimator further from the middle of Mid-Wave infrared visual field.

2) The CCD lens distortion was another crucial factor for the system precision.

3) The higher the resolution, the finer the detail that can be seen, error might be caused by resolution of image sensor in image acquisition system.

4) Noise source might cause noise during the images acquisition, which could not be denoise clearly.

5) In the process of image processing, many valid pixels might be lost, thus to improve the testing accuracy, optimized arithmetic should be applied.
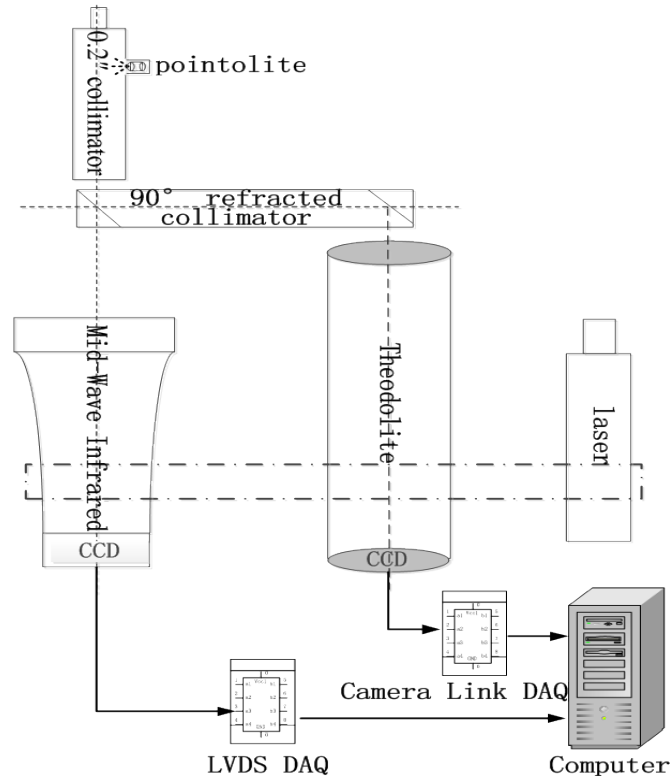

Figure 1. The former image processing method.

The resolution of theodolite system was 0.44″, while the Mid-Wave infrared system was 15.5″, so the main factor that affected the system precision was image processing of Mid-Wave infrared system. **Figure 2** demonstrated that the crosshair of 0.2″ collimator imaging in the theodolite system, which was not conducive to improve the accuracy of image processing.

Actually, during the experiment, the crosshair of 0.2″ collimator imaging in the Mid-Wave infrared was blurring. The analysis result indicated that when crosshair reflect through 0.2″ collimator and 90° refracted collimator, the illuminance and thermal radiation underwent great loss, consequently, images could not meet the accuracy requirement.

3. Improvement Detecting Method of Optical Axes Parallelism

Since images with low quality and image processing with low accuracy, some steps were taken to improvement light source and image processing method.

3.1. Design of Detecting Method

After theoretical analysis and study, two methods were intended to apply to replace 0.2″ collimator, which were laser combine with frequency multiplier and halogen tungsten lamp match with lens that can converge light [3]. By analyzing the scale of efficiency and cost of the two methods, halogen tungsten lamp match with lens would be the best choice. The result showed that the halogen tungsten lamp could image a small point in the Mid-Wave infrared CCD, hence, the image could be processed simply and conveniently. The experimental site and image in the Mid-Wave infrared CCD shown in **Figure 3**.

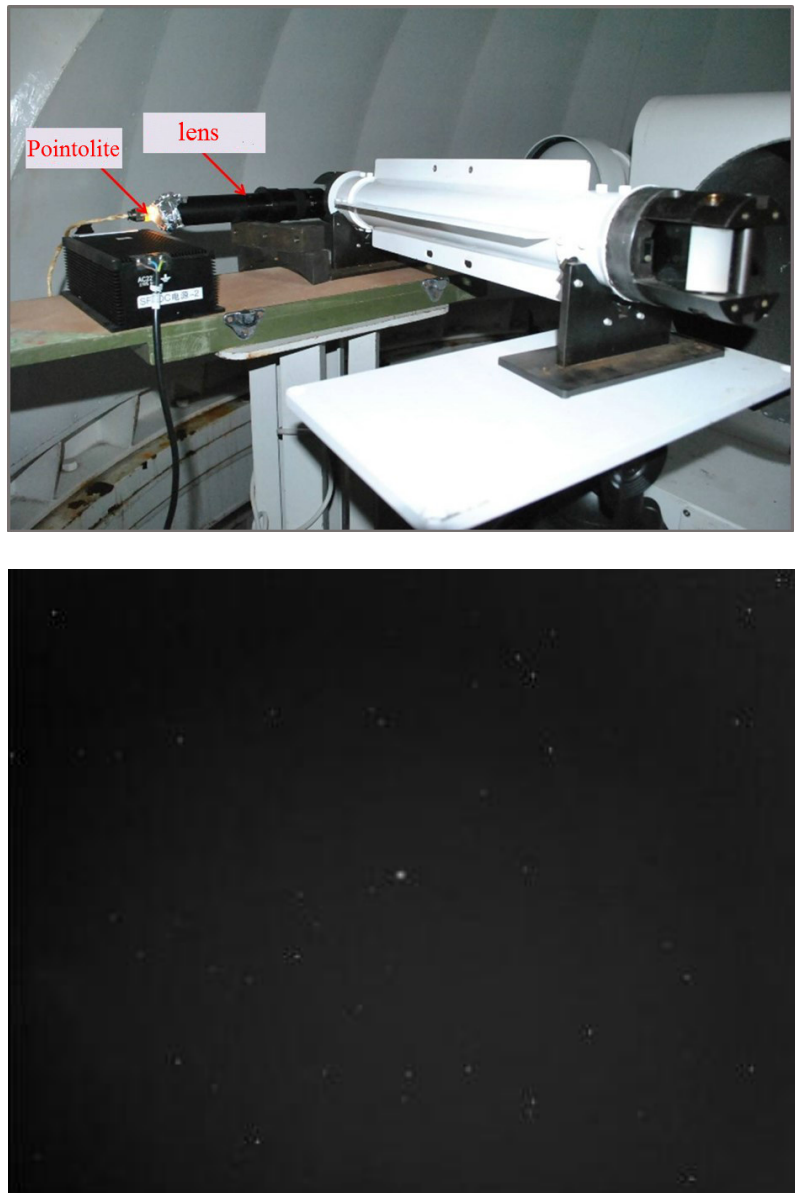**Figure 2.** Image acquired by former image processing method.

Figure 3. Program improvement test and result.

3.2. Optical Axes Parallelism Test

The experiment was carried on in the early morning, when tide and crew' activities had minimum effect on ship movement. Firstly, setting the testing support on the transition section of theodolite, and fixing the halogen tungsten lamp and lens in the testing support. Secondly, adjusting position between the lens and theodolite, till the point light in the vision field of Mid-Wave infrared CCD. Thirdly, adjusting the 90° refracted collimator to support the point light into the vision field of theodolite CCD. And then, turning the computer power on, the camera link DAQ card and LVDS DAQ card started to acquire the images and store in the hardware. Finally, transmitting the point light imaged in the two systems to the software, where the middle of the point light would be calculated.

By compared many advanced methods on image processing, the adaptive gradient threshold anisotropic filtering algorithm was chosen to suppress the infrared complex back-ground [4], filter out the noise effectively and enhance the point light target, and the result was shown in **Figure 4(a)**. After filtering, mouse was used to click the centre of point light target, and the program could build a fixed window with 12 pixels × 12 pixels for feature extraction, which was shown in **Figure 4(b)**. Finally, centrobaric arithmetic was used to calculate the point light target in the fixed window, and the result was shown in **Figure 4(c)**.

3.3. The Result of Optical Axes Parallelism Test

The optical axes parallelism could be expressed as follow formula according to principle of optical system [5].

$$\begin{cases} \Delta A = \dfrac{1}{n}\sum_{i=1}^{n}\left(x_{1i}*\theta_1 - x_{2i}*\theta_2\right) \\ \Delta E = \dfrac{1}{n}\sum_{j=1}^{n}\left(y_{1j}*\theta_1 - y_{2j}*\theta_2\right) \end{cases} \tag{1}$$

wherein, ΔA and ΔE were axes parallelism of azimuth axis and pitching axis of theodolite and Mid-Wave infrared optical systems, while θ_1 and θ_2 were angular resolution of the two optical systems, and x_1, x_2 were azimuth pixels of the two optical systems, similarly, y_1, y_2 were pitching pixels of the two optical systems, and n was data recording times.

The data in **Table 1** was brought into Formula (1), then the optical axes parallelism of theodolite and Mid-Wave infrared optical systems is (−18.89″, −24.43″).
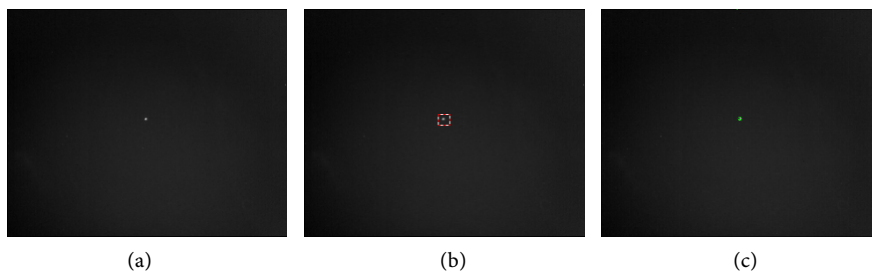

| (a) | (b) | (c) |

Figure 4. Target extraction processing. (a) Image denoise; (b) Fixed window; (c) Result achieved.

Table 1. Experimental results.

Pixels record times	Theodolite		Mid-Wave infrared		Optical axes parallelism (″)	
	x_1	y_1	x_2	y_2	ΔX	ΔY
1	254	116	8	5	−12.24	−26.46
2	264	121	9	5	−23.34	−24.26
3	248	90	8	4	−14.88	−22.4
4	260	85	9	4	−25.1	−24.6

4. Error Analysis and Results Comparison

4.1. Relationship between Optical Axes Parallelism and Angle Measurement Error

Relationship between optical axes parallelism of the two optical systems and angle measurement error could be expressed as Formula (2) [6].

$$\begin{cases} \delta_A = \Delta A \\ \delta_E = \Delta E / \cos E_c \end{cases} \tag{2}$$

wherein, δ_A and δ_E were the error caused by optical axes parallelism, while E_c was elevation angle of theodolite.

4.2. Results Comparison of Image Processing

Image processing method was the key technology which had main effect on detection accuracy. A video and image processing software was used to detect the images which also processed by the improvement image processing method. The software could judge the change of miss distance of target by dealing with continuous frames images, which would help to eliminate the error caused by small displacement of target. The judgement of software had two methods, which were manual and automatic. Manual way was used to process fine and homogeneous target, which could achieve high image processing precision. The experiment was carried on under quasi-static condition, as a result, the ship swung periodically, similarly, the miss distance of target was periodic. The square root of the average of squares of miss distance could truly reflect the position of target. The real-time result was shown in **Figure 5**.

Series images were proceed by sending to the software as shown in **Figure 6** which recorded in 5 minutes. The processing results showed that the miss distance of Mid-Wave infrared target was ($-14.21''$, $-17.02''$), which within 10'' of
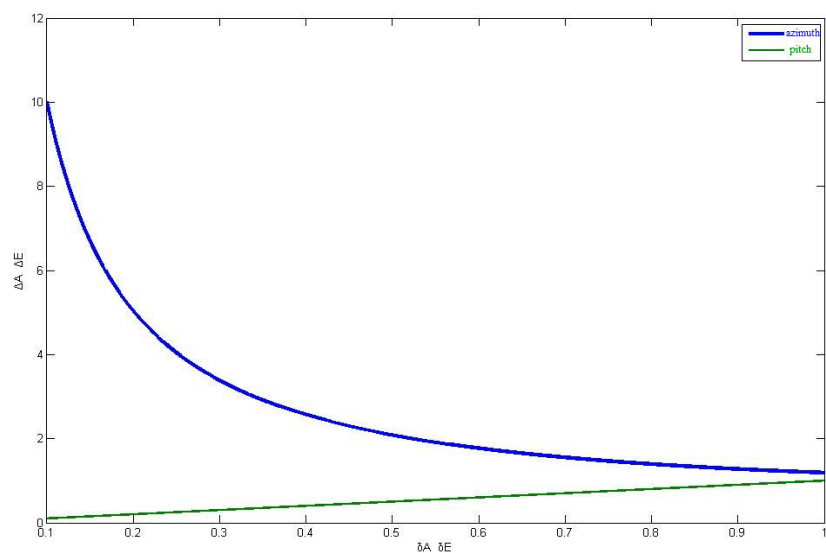

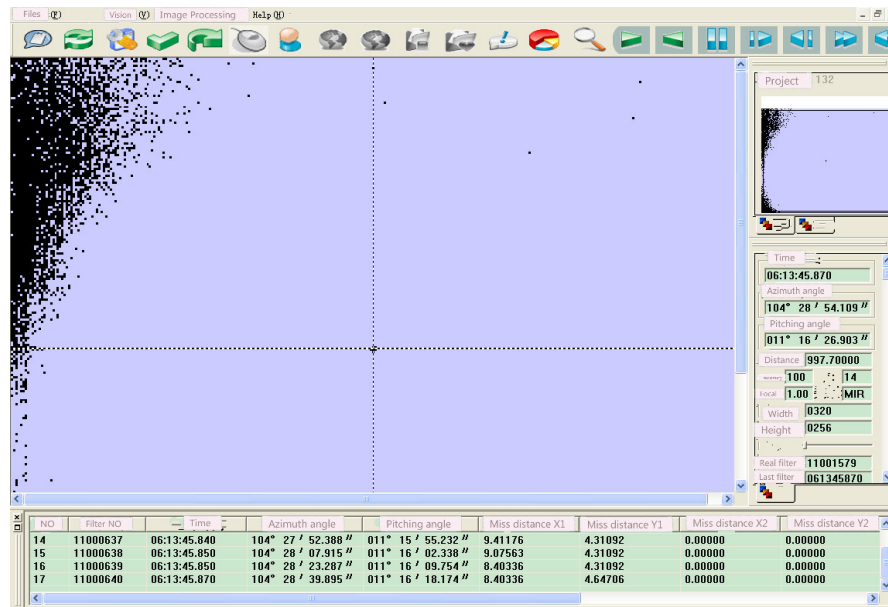**Figure 5.** Relation graph of optical axes parallelism and angle measurement error.

Figure 6. Processing results of software.

the result of this experiment.

5. Application and Prospect

The experiment showed that the improvement detection method improved imaging quality and optimized the image processing steps, which ensured its high precision and real-time performance. The follow-up work was accuracy verification, which should be carried out in the four quadrants of CCD, and accuracy verification results determined according to the consistency of the error.

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