

Measurement of slight angle of ship board dynamic platform based on bi-Fresnel prisms

Guo Minmin, Nie Yongming, Xie Longzhi

China Satellite Maritime Tracking and Control Department, Jiangyin, 214431, China

e-mail: nwy1986@163.com

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Abstract. Ocean space tracking ship will produce dynamic elastic deformation due to many factors such as solar radiation, mechanical vibration, shock waves and so on, which can affect the measurement accuracy of shipboard measurement equipments. So investigating the slight angle measurement system of shipboard dynamic platform has practical significance. In order to resolve this problem, the noncontact small angle optical measurement technology with high accuracy and measurement resolution is selected, and a setup based on a unique Fresnel double-prism and a high-resolution CCD camera is proposed. Using image processing technology the measurement accuracy of the system can be improved. The setup we proposed here is compact, easy to install, with good reliability and high precision, which has important reference value on the designing of second-class angle measurement system of the ability to detect angle smaller than one second.

Introduction

In order to improve the measurement precision of shipboard monitoring and controlling system, the hull deformation should be detected in real time. Normally, the deformation measurement methods include inertial measurement matching method [1], the strain sensor measurements [2], optical measurement method [3], and the imaging measurement method [4, 5]. More than ten years ago A. V. Mochalov proposed inertial measurement matching method, which had caused more and more attentions. Both at home and abroad, many units are active in the research and have made some progress. However, the disadvantage of this method is that the system is too expensive, which has not been widely used [1, 6]. At present, many research institutions are doing their best to detect the deformation based on the strain gauge sense method, however, the results are poor and the disadvantage of this method is that temperature compensation is in demanding. Moreover, there is a problem unable to distinguish the coupling wavelength [2, 6]. Changchun Institute of optics proposed shipboard large steel pipe for deformation detecting, which provides simple principle, high accuracy and the technology is mature. However its drawback is that the large steel pipe equipment is heavy, bulky, which can not be copied to the radar vertical deformation monitoring [6]. Video measurement method used camera has a non-contact advantage with high-precision, which is developing rapidly in recent years. Jiang Guangwen of University of Defense Technology proposed pose relay videometrics method with camera-series for ship deformations measurement, which solves two or more illogical problems and is new progress of science in the area. In this paper, based on research on the unique optical properties of Fresnel bi-prism, using a high-resolution CCD camera, a dynamic platform small angle measurement system is designed. And then theoretical analysis and numerical simulation of the system are given. The system we proposed here is compact and easy to install, which has good reliability and high precision. Moreover, the cost is lower. All properties above have important reference value for the design and improvement of dynamic angle measuring system with precision better than arcsec.

Theoretical analysis

A. Principles of the optical system

The diagram of the shipboard platform slight angle measuring system based on Fresnel bi-prism is shown in Fig. 1.

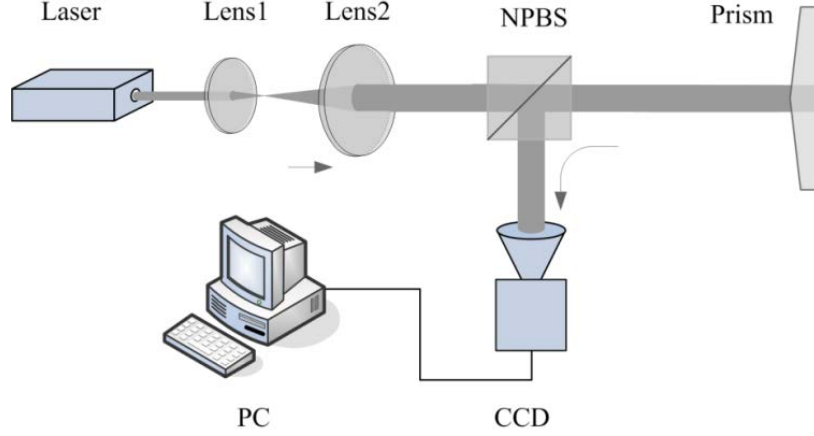


Figure 1. Angle measurement setup based on Fresnel bi-prism

Light with wavelength λ coming from a laser is converted into a parallel beam after collimator lens. Then the beam is reflected by the Fresnel bi-prism and the interference pattern is formed on the receiving surface of CCD. When the platform of the Fresnel bi-prism's body angle is changing, the interference pattern of CCD will change accordingly. According to the interference pattern's changing, the changing angle can be calculated and the specific algorithm is as following.

Assuming the angle between the two reflecting surfaces of the Fresnel bi-prism is 2φ as shown in Fig. 2. It should be proposed that the angle is enlarged for clarity.

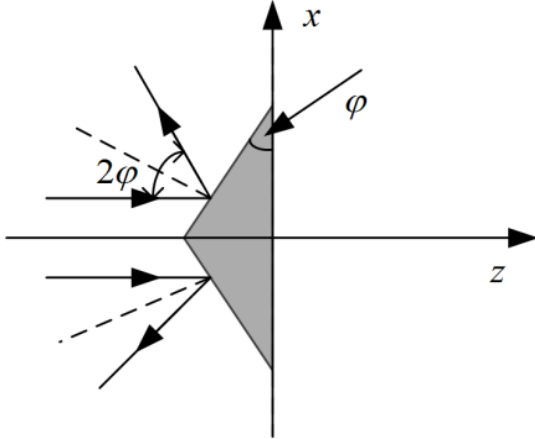


Figure 2. The optical property schematic of the Fresnel bi-prism

Providing in the CCD view field the pitch of the parallel interference fringes is d , the distance can be expressed as:

$$d = \frac{\lambda}{\sin(2\varphi)} \quad (1)$$

When the body combining with the Frenels bi-prism rotates in the space, the CCD interference fringe image also changes accordingly. Providing the optical axis direction is z-axis. The x, y and z axis follow the right hand rule and y-axis is assumed as a center axis. The rotation angle is θ in the xz plane. The interference fringe distance in the CCD view field can be written as:

$$\Delta d = f \tan(\theta) \approx f \theta \quad (2)$$

Where $\theta \ll 1$, i.e. the angle is much less than 1.

B. 2.2 The basic principles of Center of Mass method

The calculation process of Center of Mass method also named centroid or center of gravity is simple, which has been widely used in image processing. The basic formula is as follows:

$$x_0 = \frac{\sum \sum x I'(x, y)}{\sum \sum I'(x, y)} \quad (3)$$

$$y_0 = \frac{\sum \sum y I'(x, y)}{\sum \sum I'(x, y)} \quad (4)$$

$$I'(x, y) = I(x, y) - T \quad (5)$$

In the formula, x_0 and y_0 is the coordinates of the centroid. $I(x, y)$ is the sample value for the corresponding pixel with coordinates (x, y) and T is the threshold value.

The Center of Mass method can be seen as a kind of target image gray value weighted calculation. Absolute value of the weights increases linearly with the distance of the target pixel image point from the gray scale center.

Numerical simulation and experimental analysis

Based on the above analysis, the design of the measurement is based on the Fresnel prism of shipboard dynamic platform slight angle dynamic simulation platform. Figures 4a, 4b correspond with the results of numerical simulation and image processing, and Fig. 4c, 4d diagrams correspond with the results of experimentation, which is captured by the CCD camera that has 1392×1040 , $6.45 \mu\text{m} \times 6.45 \mu\text{m}$ pixels, a Dolphin F-145B modal 12 bit product of AVT Company. The interference optical intensity distributions of the CCD camera are demonstrated in Figures 3a and 3b. Using image processing technology the measurement accuracy of the system can be improved. Based on the intensity distributions in figure 3 and Matlab software the simulating and experimental results analysis of the measuring setup can be given subsequently.

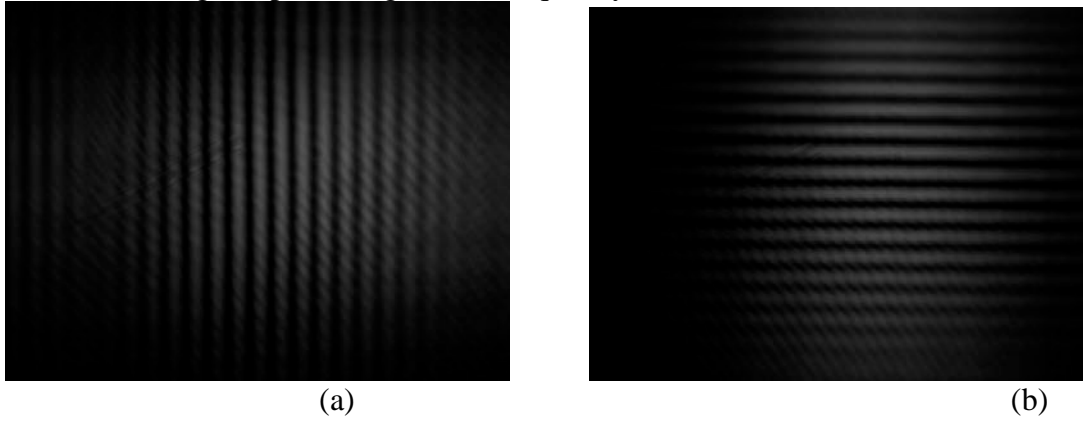


Figure 3. Interference optical intensity distributions of the CCD camera

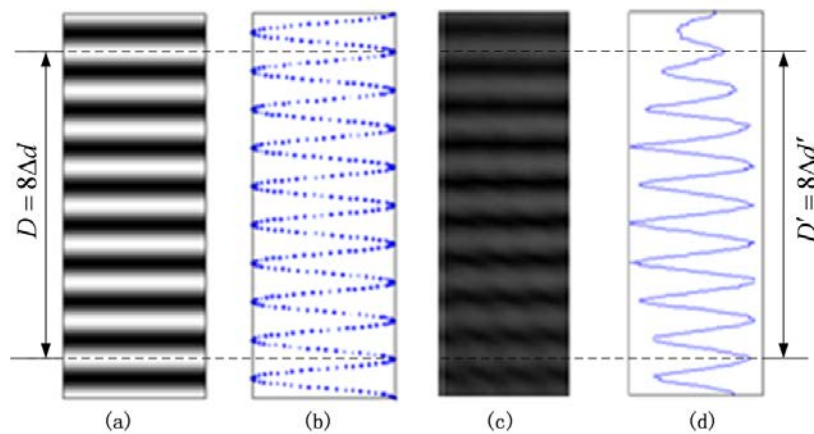


Figure 4. Simulating and experimental results of the measuring setup

Calculating results indicate that the theoretical precision can be smaller than one second and the experimental precision is about ten seconds which can satisfy the actual requirement of the space tracking ship.

Summary

In this paper, the Fresnel biprism of unique optical properties is used to achieve a slight angle of shipboard dynamic measurement platform. Both the theoretical analysis and experimental results show that the method is effective measurement accuracy which can satisfy the actual requirement. Further investigating indicates that combining with image processing technology, the measurement accuracy can be further improved. This design of the setup structure is compact, easy to install, good reliability and high precision.

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