Improved Ship Deformation Measurement System Based on OCC

Fang ZHAO, Xiao ZHANG, Jianjun ZHAO, Yi WANG
Department of Armament Science and Technology, Navy Aviation University, Yantai, Shandong 264001, China
850119362 @qq.com

Abstract. With the development of image sensor frame rate and the intelligent terminal embedded camera, the Optical Camera Communication technology (OCC) which developed from the existing image sensor is being applied in more areas. Based on the principle of OCC technology and the research of 3D ship deformation measurement system, an improved 3D ship deformation measurement scheme is put forward. The hardware structure of the system is improved by using data simulation, and the time unit is integrated into the system by using infrared communication technology, and the circuit design is also carried out. The results show that the improved measurement system has lower hardware complexity and higher availability.

1. Introduction

The ship is not an absolutely rigid, in the interaction of various internal and external factors, it will have three-dimensional deformation [1,2]. As shown in Figure 1, in the initial state, the coordinate axes in each coordinate system are in the same direction, but the deformation makes the 3D attitude of weapon system and detector coordinate system change. The relative changing attitude of the coordinate system around the $z$ axis, $x$ axis and $y$ axis are called yaw angle, pitch angle, and roll angle. A large number of experimental results show that the ship deformation seriously affects the combat effectiveness of weapon systems [1]. In order to improve the operational effectiveness of weapons, it is necessary to measure and compensate the 3D ship deformation in real-time.

![Figure 1 Influence of ship deformation on detector and weapon](image_url)

In order to realize the precision measurement of 3D ship deformation, commonly used methods include non-optical measurement method of GPS measurement [3], strain sensor measurement [4] and inertial measurement [5], and optical method of polarized light energy measurement [6], large steel pipe measuring method [7], camera measurement method[8] and star sensor measurement. The
measurement methods are compared in the paper [9]. The results show that the accuracy of optical measurement method has obvious advantages than the non-optical method. In the optical measurement method, the accuracy of the measurement method based on self-collimation principle can reach arc-second degree, and the 3D ship deformation measurement system based on collimated conjugate optical structure can measure the roll angle. This paper put forward a further improvement plan based on the research and analysis of this system.

2. Ship Deformations Measurement System Based on Optical Structure

2.1. System Introduction

The structure and principle of 3D ship Deformations measurement system based on collimated conjugated optical structure are shown in Figure 2 [9].

The system uses collimated conjugate optical structure: LED light of emitting unit of through the projection target (cross line or dot matrix) transmits in the optical channel, and imaging on the photosensitive surface of the detector. Use image processing method to extract line or positioning of the target image, the yaw angle and pitch angle are got by displacement of image center coordinate, and the roll angle is got by the image angle equation.

The system not only has measurement advantages of yaw angle and pitch angle, but also realizes the measurement of roll angle. The accuracy and stability of this system have been verified by static performance test and actual ship experiment. It can be used for 3D ship deformation measurement and real-time monitoring.

![Figure 2 Ship Deformation Measurement Scheme Based on Collimated Conjugate Optical Structure](image)

2.2 Measuring System Analysis and Improvement Needs

Based on the analysis of ship 3D deformation measurement system, further improvement requirements are proposed:

(1) The measurement system needs to set up pipelines that make the equipment too large and complex; and reserved space of deck has highly requirement.

(2) The light source adopts LED visible light with a central wavelength of 680nm~700nm. If the pipeline can be cancelled, we should also take into account the external light can produce background noise in transmission of visible light. The receiving unit should redesign.

(3) The measurement system needs to set up GPS device for time synchronization, it will increase the wiring complex; GPS signal is also prone to interference with radio signals of detection equipment.

The structure of the improved system is shown in figure 3.
From the figure 3, we can see that this paper is mainly focus on the hardware improvement of the measurement system. The mainly improved aspect is to integrate time unit into emitting unit and receiving unit, and cancel the optic pipeline. Therefore, the next part will focus on these two aspects.

3. Improvement Scheme of 3D Ship Deformation Measurement System

3.1 Time Unit Based on OCC Technology

3.1.1 Working Principle

Emitting unit uses the infrared LED of 830nm band, time information is transmitted to the drive circuit through the encoder, driving circuit controls the light source flashing, bright indicates ‘1’, and dark means ‘0’.

The receiving unit adopts infrared lens camera with filter. The receiver takes pictures at 100 frames per second to decode the signal from the optical signal to the digital signal. A gray threshold is set, greater than the threshold is ‘1’, smaller is ‘0’, process the image to obtain digital signal and decode the time information. For the 8bit depth million pixels gray image, the image size is 1M, the general fast Ethernet can meet the transmission requirements. Therefore, the average laptop can meet the system requirements.

In measurement frequency, the ship deformation period usually is 3s~10s [10]. According to the Nyquist Sampling Theorem, when the sampling frequency is greater than 2 times the highest signal frequency, the sampled data can completely preserve the original signal information. Therefore, 1Hz measurement frequency can completely preserve the ship’s deformation information. Then a two-dimensional list of time and image is obtained by selecting the first frame image and the corresponding time information. Finally, the list is transmitted to the information processing unit to resolve the 3D deformation angle.

Since the receiving unit only needs to increase the time signal decoding program in information processing unit, the design of the optical communication drive circuit in emitting unit is mainly introduced in this paper.

3.1.2 Design and Implementation of LED Driver Circuit for Optical Communication

The serial digital pulse signal is a signal format suitable for light transmission. At present, most LED driver circuits are mainly used in LED lighting and provide LED screen backlight, switching frequency is very low, can’t be used to transfer time information, or other digital signals that require higher speed, and infrared LED module drive voltage, current and other indicators more stringent than ordinary LED. To transmit the time information signal through LED, a high-speed, stable and reliable LED drive circuit must be designed.

The main function of the drive circuit is to radiate the information by modulating the pulse signal to the optical signal by controlling the light source. A constant current source infrared LED driver circuit is designed, as shown in figure 4. The pin and function of DD311 that the circuit core chip is
shown in figure 5 and figure 6.

Figure 4 Schematic of Driving Circuit

Figure 5 Block Diagram of DD311

Figure 6 Sketch Map of DD311 Pins

The LED module transmit power is usually adjusted to rated power to extend service life. The digital time signal is sent from the SMA header of the J4 or J3 to the enable end of the DD311 to complete the decision. Schmidt flip-flop consists of voltage comparison chip 74HC14, used for inverting the signal, when there is no time signal input, the DD311 output high voltage, LED is not bright, to prevent LED bright without signal. The infrared LED light source can be used to drive the time signal and pulse signal, so as to provide accurate time information for ship 3D deformation measurement.

3.2 Improvement to Optical Pipeline of Ship Deformation Measurement System

The optical pipelines of measurement system are mainly to prevent the influence of atmospheric
turbulence. In order to explore the necessity of optical pipeline, this paper makes simulation analysis and theoretical demonstration of the influence of atmospheric turbulence on the measurement results. In order to form a good contrast effect with the improved measurement results, the basic parameters of the system, such as object lens focus, measurement distance, target image specifications and image processing algorithms, are not changed.

### 3.2.1 Effect of Atmospheric Turbulence on Measurement System

The influence of the atmospheric turbulence on the system is simulated. The Monto-Carlo random phase screen is used to simulate the atmospheric turbulence function $\phi(u,v)$:

$$\phi(u,v) = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} c_{n,m} \exp\left[\frac{1}{2\pi}(f_{n,u}u + f_{n,v}v)\right]$$  \hspace{0.5cm} (1)

In the formula:

$$\left\langle f_{n,u}\right\rangle = \Phi_{\phi}(f_{n,u};f_{n,v})\Delta f_{n,u}\Delta f_{n,v}$$  \hspace{0.5cm} (2)

$$\Phi_{\phi}(f_{n,u};f_{n,v}) = 0.023r_0^{5/3}\exp\left(-\frac{f_{n,u}^2}{f_0^2}\right)\left(\frac{f_{n,u}^2 + f_0^2}{f_0^2}\right)^{1/6}$$  \hspace{0.5cm} (3)

$$r_0 = (0.423k^2C_n^2\Delta z)^{3/5}$$  \hspace{0.5cm} (4)

$\Phi_{\phi}(f_{n,u};f_{n,v})$ is the energy spectrum density function obeying the Gauss distribution, $\Phi_{\phi}^{MK}(f)$ is the Modified von Karman model of $\Phi_{\phi}(f)$; $r_0$ is the coherent length of the atmosphere, $k$ is a wave vector, $\Delta z$ is the light wave propagation distance, $C_n^2$ is the refractive index structure parameter.

$C_n^2$ is a parameter used to describe atmospheric turbulence intensity, increases with atmospheric turbulence. Create the dot image according to the wave propagation process considering atmospheric turbulence, then get the 3D deformation angle from the image features. The difference between measured angle and preset angle is the measurement error. The relationship between $C_n^2$ and the standard deviation of 3D deformation angle are obtained by simulation, the results are shown in figure 3:

![Figure 7 Error Standard Deviation of 3D Deformation Angles under Different Atmospheric Turbulence Intensities](image)

As the figure shown, the standard deviation of the 3D deformation angle increases exponentially after the atmospheric turbulence reaches a certain magnitude. When $C_n^2$ reaches $10^{-12}m^{-2/3}$, the standard error of the yaw angle and pitch angle is no more than 3", while the roll angle reaches 18". This proves that the effect of atmospheric turbulence on roll angle measurement results is greater than yaw and pitch angle. Therefore, the optical protection channel is mainly to ensure the measurement accuracy of the roll angle, which is consistent with the analysis of the original literature.
At the same time, from the analysis of the experimental results, we can see that when the atmospheric turbulence intensity is suppressed at \( C_n^2 = 10^{-14} \text{m}^{-2/3} \), the error standard deviation of the 3D deformation angles is less than 1”, which meets the requirements of the measurement system. Thus, when atmospheric turbulence is at \( 10^{-14} \text{m}^{-2/3} \) orders of magnitude or less, the effect of atmospheric turbulence on 3D deformation measurements can be neglected.

### 3.2.2 Statistical Analysis of Measurement System Atmospheric Turbulence Characteristics

At present, we have established testing stations in four typical areas: offshore (Yantai), large cities (Beijing), plateau environment (Chengdu) and tropical environment (Guilin), to collect atmospheric test data. Through the comparison and analysis of the data in the database, the necessity of the optical pipeline in the measurement system is discussed.

According to test plan, recorded the value of \( C_n^2 \) for one year in coastal areas and compared them with other conditions. At present, the Davis inequality is widely used to distinguish the turbulence intensity according to the \( C_n^2 \) value, the formula is:

- Strong turbulence: \( C_n^2 > 2.5 \times 10^{-13} \text{m}^{-2/3} \)
- Medium turbulence: \( 6.4 \times 10^{-17} < C_n^2 < 2.5 \times 10^{-13} \text{m}^{-2/3} \) \hspace{1cm} (5)
- Weak turbulence: \( C_n^2 < 6.4 \times 10^{-17} \text{m}^{-2/3} \)

Because of space reasons, the specific test data is not displayed, only take the conclusion. The statistical analysis shows the minimum, mean, and maximum distributions of \( C_n^2 \) in four seasons, the results are given in table 1.

| Season | minimum/m-2/3 | mean/m-2/3 | maximum/m-2/3 |
|--------|---------------|------------|--------------|
| Spring | 3.09×10-15    | 6.81×10-15 | 1.04×10-14   |
| Summer | 9.23×10-16    | 1.93×10-15 | 3.26×10-15   |
| Autumn | 5.16×10-16    | 1.53×10-15 | 2.82×10-15   |
| Winter | 1.04×10-15    | 2.25×10-15 | 3.77×10-15   |

From the results we can see that \( C_n^2 \) mean value of offshore area are basically at \( 10^{-15} \text{m}^{-2/3} \) orders of magnitude, by the conclusion of section 3.1.1, atmospheric turbulence effect on the measurement of 3D deformation angle is negligible, so the optical pipeline of original system can be cancelled.

### 4. Conclusion

Through the research on ship deformation measurement system based on collimated conjugate optical structure, a hardware improvement scheme is proposed. The improvement to ship deformation measurement system is mainly from the aspect of increasing system availability and decreasing hardware complexity. By data simulation and verification, cancel the optical pipeline, and integrate the timing unit into the emitting and receiving unit based on infrared communication, further reducing the hardware complexity.

Furthermore, by increasing the image gray level and improving the accuracy of the image positioning algorithm, it is also helpful to suppress the atmospheric turbulence error and improve the measurement accuracy of the roll angle. In this paper, in order to highlight the advantages of hardware improvements, software improvements are not discussed together, and they can be further discussed in the future research.

### References

[1] Day D L, Arruda J. Measuring structural flexure to improve precision tracking[R]. DTIC Document, 1996.
[2] Luan Y N, Jiang Y W. Measurement and analysis of ship deformation [J]. Ship Argumentation,
2003(3): 17-22.

[3] Lachapelle G, Cannon M E, Lu G, et al. Shipborne GPS attitude determination during MMST-93 [J]. Oceanic Engineering, IEEE Journal of, 1996, 21(1): 100-104.

[4] D ’Emilia G, Iaconis F. A simple fiber optic sensor for angle measurement [C]. 1994: 295-299.

[5] Lu Y, Cheng X. Random misalignment and lever arm vector online estimation in shipborne aircraft transfer alignment [J]. Measurement, 2014, 47: 756-764.

[6] Astheimer R W, Daley W J. Two axis autocollimator using polarized light [P]. 3316799. May 2, 1967.

[7] Liu X M, Zhang Y Y, Feng X Y, et al. A Novel Method for Hull’s Three Dimensional Deformation Measurement [J]. Applied Mechanics and Materials, 2013, 344: 93-98.

[8] Chao Z, Yu Q, Jiang G, et al. Study of a pose-relay videometric method using a parallel camera series [J]. Applied Optics, 2010, 49(28): 5192-5198.

[9] Gao Y. Research on Key Technologies of 3D Ship Deformations Measurement Based on Collimated Conjugated Optical Structure [D]. National University of Defense Technology, Changsha: 2015.

[10] Jian S L, Fei J B, Liu B. Introduction to the measurement and control technology for space tracking ship [M]. Beijing: National Defence Industry Press, 2009: 145-152.