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Structural Parameters Optimum Design of the New Type of Optical Aiming System

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Abstract: Combination of gyro north-finder, self-collimation photoelectric theodolite can be composed a ground rapid directional aiming system. In the paper, based on the CCD angle measurement technology, the self-collimation optical system is redesigned, focal length of the optical system is calculated, and the appropriate parameters are chosen. Optical conjugate design of the three light paths of light source module, visual module, and CCD receiving module is adopted to synchronize the transmission beams of the three light paths. The simulation and optimum design of light paths in the optical system are achieved by using the ZEMAX software. By analyzing the spot diagram and modulation transfer function (MTF), appropriate structural parameters of the optical system suitable for aiming working conditions are obtained.

Keywords: Aiming, CCD, optical parameters, optimum design, self-collimation.

1. INTRODUCTION

A ground rapid directional aiming system is the technical support for the launching system. The orientation and aiming [1, 2] of the initial firing can be achieved by using integrated design technology of gyro north-finder and self-collimation photoelectric theodolite. After deep analysis of the new aiming system's requirements, a new optical collimation system should be developed. Especially the optical collimation system, electric control system and structural system of previous photoelectric theodolite should be optimally redesigned. In the paper, based on the CCD angle measurement technology, the self-collimation optical system is redesigned, focal length of the optical system is calculated and the appropriate parameters are chosen. Optical conjugate design of the three light paths of the light source module, visual module and CCD receiving module [3] were adopted to synchronize the transmission beams of the three light paths. The simulation and optimum design of light paths in the optical system were achieved by using the ZEMAX software. By means of analyzing the spot diagram and modulation transfer function (MTF), appropriate structural parameters of the optical system suitable for aiming were obtained.

2. THEORY OF THE SELF-COLLIMATING OPTICAL SYSTEM BASED ON THE CCD ANGLE MEASUREMENT TECHNOLOGY

The CCD self-collimating optical system was achieved by using the principle of CCD sensitive optical signals. The self-collimating optical system is shown in Fig. (**1**).

The optical system consists of LED light source, reticule, splitting prism, lens and CCD arrays [4, 5]. The LED light source evenly illuminates the reticule and the reticule is formed with a uniform measured slit. Reticule is placed in the focal plane of the optical system, after passing through the object lens, a parallel beam is formed and projected onto the reflector. The beam is reflected back to the self-collimation optical system by the reflector, and then an image is formed in CCD after the beam passes through the beam splitters.

If the reflector is perpendicular to the main axis of the autocollimator, the beam will turn back. When the reflector changes an angle of α, the reflection light will return which forms an angle of α with incident light, an image will be produced in different positions of CCD according to the angle of α. According to the principle of the trigonometric function:

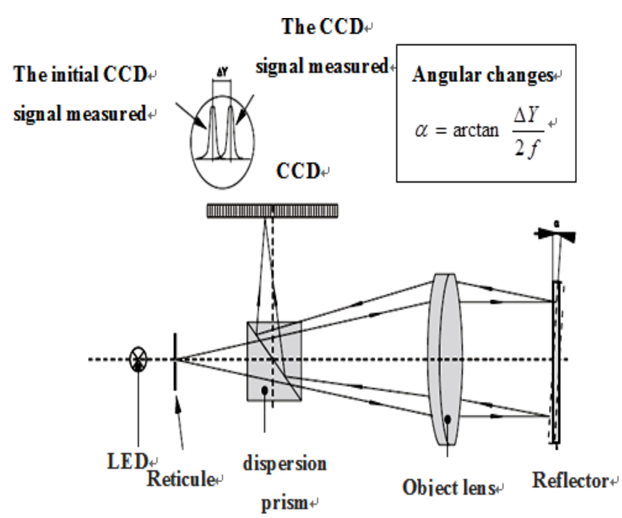

Fig. (1). Principle of photoelectric autocollimator.

Table 1. Basic parameters of TCD1500C CCD image sensor.

name	index
*Pixel	5340
*Pixel size	14μm ×14μm
*Sensitivity	4.8V/lx.s
*Saturation exposure	0.3lx.s
*Working temperature	-25ºC~+60ºC
*Stock temperature	-40ºC~+100ºC

$$\tan 2\alpha = \frac{\Delta Y}{f} \quad (1)$$

When α is small, it can be considered that , so the formula 1 can also be given as:

(2)

The measured angle α will be gained:

(3)

Therefore, the deflection angle of reflector can be measured by measuring the changes of the CCD image, namely ΔY.

3. DESIGN OF THE LIGHT PATH

3.1. Design of Optical Index

Photoelectric self-collimation system works according to the change of the position of sensitive beam, so the quality of the optical system was directly related to the measurement precision of the self-collimation photoelectric theodolite. The design of the optical system was based on the CCD index, relative aperture, field angle, etc. [6, 7].

The CCD used in this project was TCD1500C linear CCD image sensor of TOSHIBA Corporation. Some CCD's specifications are shown in Table **1**.

It is required that the accuracy of the self-collimator meet 1", so the measurement accuracy must be at least 0.1". The exposure pixels should be increased as much as possible so that the gravity center can be calculated more accurately, by using gravity model appoach. If each pixel chosen represents 15", it can be subdivided into more than 100 for the binarization processing of the control system and software subdivision, so the resolution designed is 0.03".

1) Focus

The focus of optical system can be calculated by formula (2):

It is required that f =241mm, which meets the demand of system resolution.

2) Field angle

The self-collimation range designed was ±20′, and the sensitive range was ±22′, after calculating the CCD measuring position was required as follows:

$$\Delta \; = 2 \, . \, \tan 22' = 3.08 \text{ mm}$$

And the field angle is 2ω, while ω is given as:

$$\tan \omega = \Delta. \; / \; . \quad (4)$$

By the formula (4), ω is equal to 44', and the value of ω selected in this design is 45', so the field angle is equal to 1°30′.

3) Magnification

Since

Where, f is the eyepiece focus. In the design, the magnification M was 30×, if the eyepiece focus is less than 8mm, the exit pupil will be too short, because the exit pupil distance is related to the eyepiece focus. Therefore, the eyepiece focus designed in this system could meet the general design requirement.

4) Clear aperture

The magnification M in the design was 30×, since the maximum angle of resolution of the human eyes (1') was approximately equal to the aperture value, and in order to alleviate visual fatigue, generally the aperture value is equal to the magnification times a number which is greater than 1. Meanwhile, in order to meet the need of CCD exposure energy, the objective aperture of foreign photoelectric theodolite is usually designed as 50mm, this kind of object lens was chosen in this design, so the relative aperture is given as:

.

5) Spectral coverage

Optical wavelengths are 380nm to 760nm. Based on the above analysis and a common occurrence in optical system are color aberration, optical aberration and distortion [7]. So these aberrations should be minimized in designing. In order to achieve the above purpose, it was necessary to simulate by using ZEMAX software which predicted good accuracy of the self-collimation photoelectric theodolite.

3.2. Selection of Optical Devices

1) Object lens

The chromatic aberration can be effectively eliminated by the three cemented lens. It was chosen as the telephoto lens in this design.

2) Eyepiece

There was aberration both in the wide beam and the light beam incident outside the optical axis, during the beam

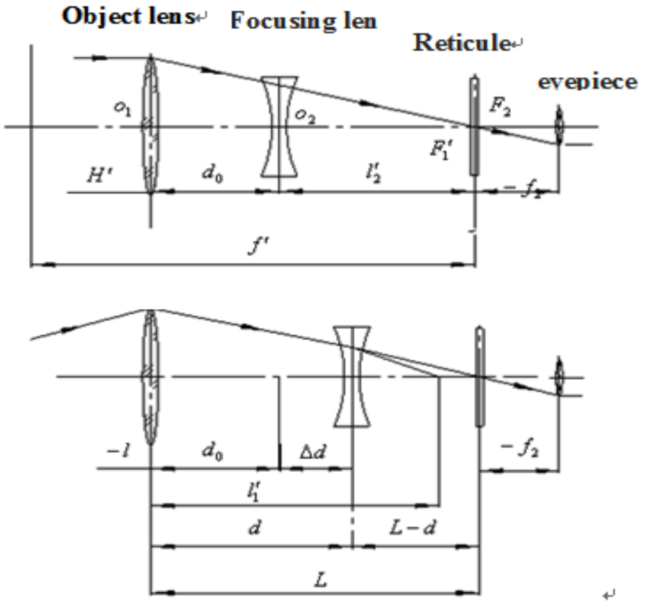

Fig. (2). Diagram of inner focusing system.

propagation process. The orthoscopic eyepiece is most widely used to eliminate distortion which is used in this design.

3) Spectroscope

To make the eyepiece and the CCD object lens receive the images focused on the focal plane of the lens at the same time, two transflective lens were added behind the three cemented lens, Optical conjugate design of the three light paths of light source module, visual module and CCD receiving module [6] were adopted to achieve the effect of synchronous imaging.

4) Focus mode

Focusing has can be achieved by two methods, external focusing and internal focusing. The internal focusing mode was used in this design. The internal focusing lens composed of the combination of combined lenses and there is a large air gap in the middle, as shown in Fig. (**2**). If the imaging objects are at different distances, the relative position of the lens will be adjusted to make the image come back to the focus point of the lens F_1 .

5) Relay system

Prism system should be used to achieve the function of changing direction and for this purpose the Abbe prism was used in this design. A reflection film is unnecessary as all the light will be reflected by the prism, saving cost.

6) Light source

The light source is an important component of the system. Divergence angle and uniformity of light are the prerequisites of high-precision measurement. The high strength LED was used in this design; uniform beam is formed while the light emitted from the LED was focused by the lens. The divergence angle of beam would be changed by changing the distance of the lenticular lens and the planoconvex lens, to achieve the effect of uniform illumination.

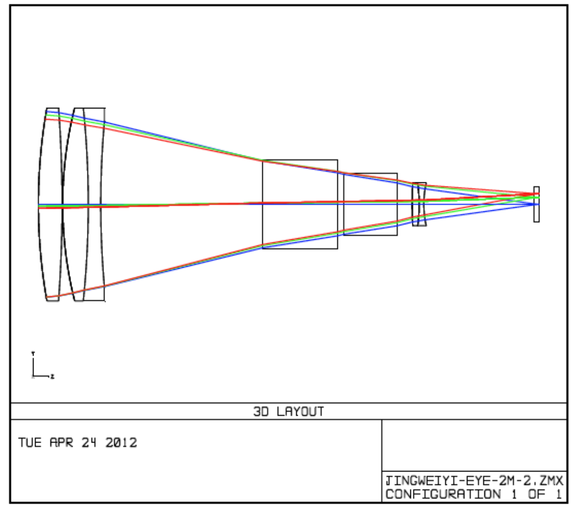

Fig. (3). Telescope system objective optical path.

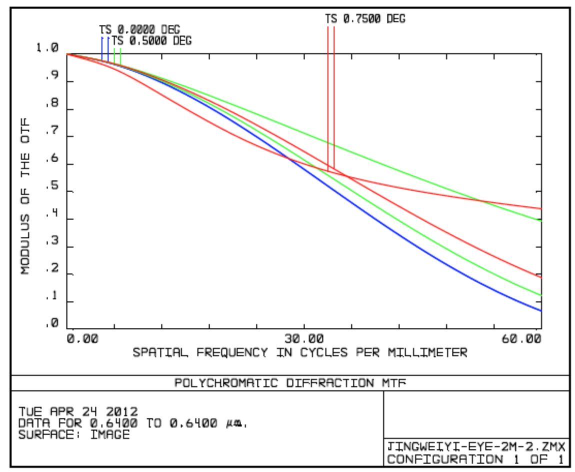

Fig. (4). MTF curves of objective lens.

4. THE OPTIMIZATION OF SELF-COLLIMATING OPTICAL SYSTEM AND THE ANALYSIS OF IMAGE QUALITY

ZEMAX is an optical design software developed by Focal Software Inc. The software has a feature of global optimization. It is based on the algorithm of reducing diffuse plaques RMS radius and the purpose is to minimize the evaluation function. Plenty of default evaluation function can be provided by ZEMAX, the optimization design can be realized by changing various parameters, indicators and calculated data.

Fig. (**3**) shows the simulation of optical path of the telescope lens by ZEMAX. The object focal length is 241mm, the eyepiece focal length 8mm. Three cemented lens were used to remove the color difference. A rectangular prism was used in this design.

Fig. (**4**) shows the Modulation Transfer Function (MTF) under three view angles. Generally, in optical system, the value of MTF is greater than 0.1 [8], MTF curves give a high contrast in low frequency and the image quality obtained is

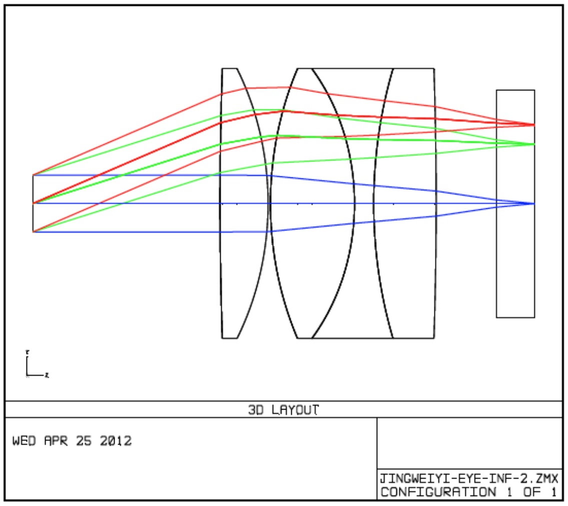

Fig. (5). Optical roadmap of eyepiece.

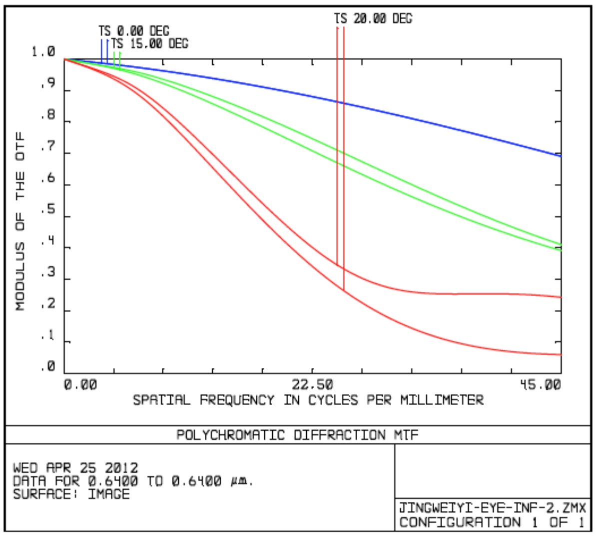

Fig. (6). MTF curves of eyepiece.

good. For the center of the field lens system, MFT value is greater than 0.1 at 60 line pairs in the spatial frequency. And the field of view between 0.5° and 0.75°, the MTF value of object lens increases, the MTF value of center field is much lower, so the MTF value of the edge is improved, which plays a role of balancing various aberrations.

Fig. (**5**) shows the optical path simulation by ZEMAX. It is a reverse simulation. The position of exit pupil (the image formed by the aperture stop) is defined as aperture stop (the minimum diameter that the light passes through the optical system).

The objects with the value of outline MTF is 0.3 can be distinguished by human eyes for its high sensitivity [9]. Fig. (**6**) shows that the value of MTF is greater than 0.05 when the spatial frequency is at 45 line pairs.

The object lens is not only a part of CCD, but also a part of LED circuit so that the light emitted from the LED will be introduced into telescope system and the image on the CCD. In Fig. (**7**), the method of curve cut-off was adopted to simulate the imaging on the CCD by ZEMAX. The beam from

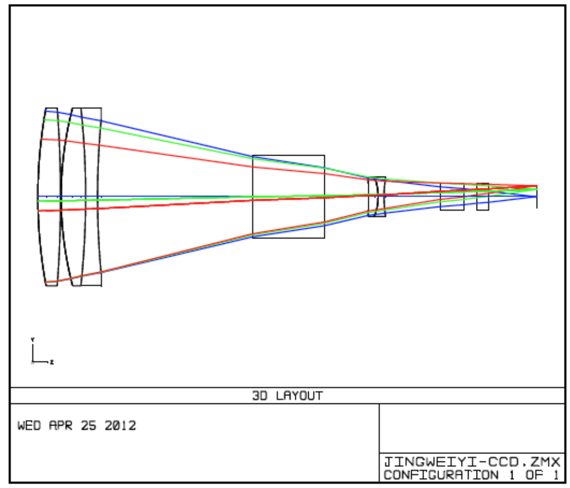

Fig. (7). Optical path of CCD receiving system.

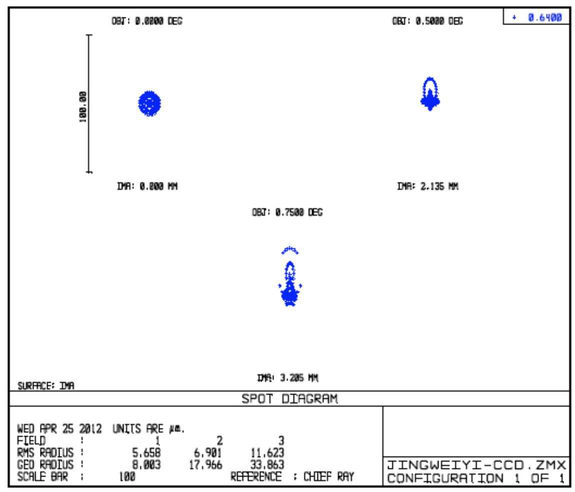

Fig. (8). Spot diagram of CCD receiving system.

infinity passes through the object lens, beam splitter prism, focusing lens, filters and forms an image on the CCD.

The structure parameters obtained through the CCD receiving system optimized by ZEMAX is shown in Table **2**.

Fig. (**8**) shows the spot diagram of CCD imaging.

RMS RADIUS (root mean square radius) is an important value. The size of typical diffuse palques can be reflected by this value and this value can also quantitatively reflect the actual spot size of the system. However, it is not the radius of all of the diffuse palques. RMS RADIUS is the most important parameters to reflect the quality [10] of diffuse. It is given as:

RMS=

is the distance between each point and beam centroid. GEO is the radius of disc of confusion which is still the maximal distance between center and the disc of confusion.

The size of spot diagram of CCD system was shown in Table **3**. The size of pixel is 14μm × 14μm, in Table **3**,

Table 2. Structure parameters of CCD receiving system.

	*Radius	*Thickness	*Glass	*Semi-diameter
Obj	Infinity	Infinity		Infinity
STO	125.3100	7.6000	BAK4	25.0331
2	-301.3000	0.2000	BAK4	24.7676
3	90.1600	8.2000	K9	24.0835
4	-211.8000	4.0000	ZF3	23.3785
5	211.8000	52.0000	ZF3	22.3662
6	Infinity	24.0000	K9	12.5593
7	Infinity	14.8000	K9	9.5400
8	-194.9800	3.2000	K9	6.7060
9	-14.0280	2.0000	BAF8	6.5296
10	32.9600	18.7000	ZK4	6.0698
11	Infinity	8.0000	ZK4	4.9200
12	Infinity	4.3000	K9	4.5863
13	Infinity	4.0000	K9	4.3137
14	Infinity	16.2000	K9	4.1468
IMA	Infinity	-		3.3206

Table 3. The sizes of spot diagram of CCD imaging system.

*Angle / *Parameter	0°	0.5°	0.75°
*RMS(μm)	5.658	6.981	11.623
*GEO (μm)	8.003	17.966	33.863

the RMS of spot diagram under three viewing angles meets the requirement of the size of pixel. And the radius of center viewing angle meets the requirement of the size of CCD. The geometric radius is still within acceptable range. In general, the design of light path of CCD imaging is reasonable.

CONCLUSION

1) The design of optical system.

According to the self-collimation theory and actual condition, the focus of optical system in this design was 241mm and the size of the clear aperture was 50mm. Based on the long-term learning and research, the internal focusing lens, three cemented lens and orthoscopic eyepiece were finally selected in this design.

2) The analysis and evaluation of the image quality of the optical system.

The optical system was simulated by the ZEMAX software, combined with the actual requirement of this design, finally, the optical modulation transfer function(MTF) and spot diagram was selected as the main means for analysis and evaluation of the image quality and various parameters and design plans meet the requirement of this design. It provides an important step for further research.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] M.A.R. Cooper, *“Modern theodolites and levels”* (Enlish, 2nd ed), London: Granad, 1982.

[2] XI C P, *“The key technology research of the optoelectric signal processing in the high accuracy electric theodolite”,* Nanjing: Nanjing University of Science & Technology, 2006.

[3] Y. Z. Wang, *“Intelligent Optoelectric systems”*, Beijng: Science

[4] T .C. Zhao*, “The design and study of CCD photoelectric auto collimation”,* Harbin: Harbin Institute of Technology, 2008.

[5] J.G. Zou, *“Research on high accuracy CCD two-axis autocollimator”,* Hefei: Hefei University of Technology, 2005.

[6] Q. Y. Wang, *“Application of CCD Technology”,* Tianjin: Tianjin University Press, 2000.

[7] Y.M. Zhang, *“Applied optics”* (3rd ed)*,* Beijing: Electronic industry press, 2008.

[8] M. Laikin, “*Lens design”* (4th revised edition), CRC Press Inc, 2006.

[9] J. Liu, and M. Gao, *“Optical design”*, Xian: Xidian university press, 2006.

[10] Y. Jun, L. Jiaming, and, Y. Jianyu, *et al*, “Distortion measurement and calibration technology for CCD camera system based on new target board”, *Acta. Optica. Sinica*., vol. 27, no. 8: pp. 1440-1442, 2007.

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