Optical Design of Small Imaging Lens with Large Field Of View Angle

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Abstract. In order to meet the application requirement of low cost micro camera with large field of view, a small imaging lens with large field of view angle was designed, and the double Gauss structure was selected as the initial structure of the system. Use ZEMAX to perform a default evaluation function and manual image quality optimization for the system. The aberration of the system is reduced by adding the high order aspherical surface. Finally, the optical system that meets the requirements is obtained. The system has good image quality with 80lp/mm frequency larger than 0.3.

1. Introduction

With the continuous application of aerial photography in the fields of agriculture, animal husbandry, meteorology, and investigation, higher performance aerial cameras are constantly being updated. In the development of aerial cameras, the testing of its performance indicators is related to the quality of aerial cameras. Therefore, the corresponding performance testing equipment of the aerial camera also needs to be continuously updated, so as to be able to accurately test and extract the performance parameters of the aerial camera, and provide a basis for the development of the camera. Based on the review of domestic and foreign patents and literatures, combined with the optimization of simulation practice, the design process of miniature large-angle optical lens used as ground test is given. The design and simulation of the optical lens were analyzed in detail, and the design was improved, the performance was optimized, and a good simulation design was made [1]. With the improvement of design, processing and testing technology, optical aspherical surface has become one of the widely used components. The proper use of aspherical surfaces in optical systems can effectively improve the imaging quality of optical lenses and improve their compactness [2]. The design of optical system is the most important technology of imaging lens, which is directly related to the imaging quality of camera [3]. Based on the deep research of double Gauss system, this paper creatively designs an small optical lens with large field of view angle imaging.
2. Optical design analysis

2.1. Initial Design Parameters
The parameters of the optical lens are as follows: focal length: $f' = 40$ mm; F number: 8; field of view: $2\omega = 50$ degree; working band: FDC light; distortion: less than 1.5%; imaging quality: 80lp/mm space frequency is greater than 0.3.

2.2. Dimensions of miniature Optical Lens with large Field of View Angle.
In the design of the whole structure of the optical system, the structure of the optical system should be designed according to the requirements [4], which is very important to the optical design, Inlet diameter of optical system:

$$D = \frac{f'}{F}$$  \hspace{1cm} (1)

In the formula, $F$ is the F number of the optical system, so $F = f'/D$, that is, the reciprocal of relative aperture [5].

It is known that the focal distance $f' = 40$ mm, $F = 8$, so the diameter of the lens can be calculated as $D = 5$ mm. Line field of view:

$$\tan \omega = \frac{y'}{f} \Rightarrow 2y' = 2\tan \omega$$  \hspace{1cm} (2)

According to the known conditions, the angle of camera view is 50° and the focal length is $f' = 40$ mm, the diagonal size of the receiver can be calculated by $2y' = 37.3$ mm.

2.3. Selection of optical system initial structure
In the initial design of lens optical system, the initial structure is selected by scaling method.

After the selected initial structure is input into the software, the size of residual aberration is obtained by the combination of operands, and the size of advanced aberration is judged. When the size of the selected structure and the design index are different, we need to scale the initial structure, and pay attention to the change of the boundary conditions when zooming. It is not allowed that the convex lens edge is too thin and the concave lens center is too thin [6].

The selection of the initial optical system structure needs to refer to the following aspects: the number of lenses, the material of the lens, the thickness of the lens and the distance between the lenses. The input basic parameters in lensview are analyzed and compared. The dual Gauss system is chosen as the initial structure of the optical system. The initial junction and the initial modulation transfer function of the system are shown in figure 1 and figure 2.
2.4. Optimization of system ratio and the materials selection

Because the target requires a small optical imaging lens with large field of view angle, the initial structure of the dual Gauss lens is scaled down to modify the pupil diameter, field angle and system wavelength. The glass material provided in the original structure is too old, replace it with a new type of glass material with better performance. The first mirror SK2 was changed to H-ZBAF50, the second mirror SK16 to H-F13, the third mirror F5 to H-ZK6, the fourth mirror F5 to H-ZK20, the fifth mirror to SK16 to F6, and the sixth mirror SK16 to H-ZBAF50. The H-ZBAF50 is suitable for the large-field angle lens. The structure of the optical system after adjusting and replacing the material is shown in figure3 and its transfer function is shown in figure4.
After changing the material and ratio, the transfer function of the optical system does not increase significantly, however it decreases. Next, by changing the lens radius of the optical system, the gap between the lenses is reduced to reduce the difference between the optical systems. Improve the imaging performance of optical system.

2.5. Optimal Design of Optical system

Through the default evaluation function optimization, a reasonable structure parameter is found, and then the manual optimization is carried out to achieve the imaging quality that meets the target requirements [7]. After the initial structure is scaled, adjusted, and the angle of view is adjusted, the focal length of the system is fixed, so that to ensure that the focal length of the optical system is invariant, the EFFL function is set to make the $f’ = 40$ mm. Set the radius of the mirror as a variable.

![Fig. 5 Radius set to variable](image)

The radius is optimized by default function, and its thickness is manually optimized because the limitation of the target. The optimized system structure is shown in figure 6.
With the optimization, it is found that the requirements of imaging quality and distortion cannot meet the design requirements at the same time, and the spherical lens alone cannot meet the requirements. Use an aspheric surface in the system. Although the processing of the aspherical surface is more complicated than the spherical surface, the only way to correct the aberration while maintaining the total number of shots is constant or less is to ensure the image quality. This design gradually optimizes the optical system by increasing the number of mirrors, increasing the number of variables and increasing the high-order aspherical coefficients [8].

The usual even-degree aspherics can be expressed as:

\[
z = \frac{cr^2}{1 + \sqrt{1 - (1 + k)cr^2}} + a_r r^2 + a_4 r^4 + a_6 r^6 + \cdots
\]  

It can be seen from the above formula that if the aspherical surface is chosen with a higher degree of aspherical surface, it will have more degrees of freedom than using a quadric surface [9]. After adjusting the surface of the second lens to aspherical surface, we gradually try to optimize and determine that the six and eight order coefficients of the high order aspheric surface are \(-7.10536567E-07\) and \(3.27786118E-08\) respectively. The final system parameters are shown in fig. 7, and the modulation transfer function is shown in fig. 8. The MTF value of 80lp/mm system is greater than 0.3, the imaging quality of the system meets the initial requirement [10].
3. Image quality evaluation

3.1. System point diagram

It can be evaluated by the optical system of dot plot. It is a convenient and feasible method to evaluate the image quality of large aberration system by using the point sequence diagram [11]. It can be seen from the figure 9 that the radius of the diffuse spot is not very large and basically meets the requirements of the system and the imaging quality.

\begin{equation}
q = \frac{Y_y - y}{y} \times 100\% = \frac{\rho - \beta}{\beta} \times 100\%
\end{equation}

(4)
The actual transverse magnification of a field of view of the optical system. The relative distortion value represents the relative error between the actual magnification of the actual optical system and the ideal magnification [12].

Figure 10 is the values of system distortion without. It can be seen that the distortion of the system is reduced and the distortion of the system is only small, which effectively improves the imaging quality of the system.

3.3. Tolerance analysis of system

In the evaluation of the system, in addition to the evaluation of the image quality of the system and the criterion of whether it meets the requirements, an important factor should be considered: tolerance, the size of which leads directly to the success of the assembly of the future product [13]. Modify the default tolerance function, select sensitivity analysis method in the tolerance settings under the tool menu, and finally perform tolerance analysis. Figure 11 shows a list of partial tolerances automatically output by ZEMAX. It can be seen from the diagram that the change of thickness is within the range of allowable values. The maximum thickness change is 0.01440314, which is acceptable for the optical system.

![Fig. 10 Distortion of the system after optimization of free form surface](image)

![Fig. 11 Thickness tolerance of the system](image)
Figure 12 shows a list of tolerances for element eccentricity. It can be seen from the diagram that the change of MTF value is mostly in the second place after the decimal point. This minor change does not affect the overall imaging performance of the system [14]. The maximum value is 0.00450666, which is allowed and has little effect on imaging quality [15].

| Element | Eccentricity | MTF Value |
|---------|--------------|-----------|
| T1      | 0.00238934   | 0.00240132|
| T2      | 0.00238934   | 0.00240132|
| T3      | 0.00238934   | 0.00240132|
| T4      | 0.00238934   | 0.00240132|
| T5      | 0.00238934   | 0.00240132|

4. Summary

In this paper, an optical system of a small camera with large field of view was designed. According to the technical specifications of the camera and based on the double Gauss system, the system is optimized by using ZEMAX, and the high order aspherical surface is creatively added to meet the requirements of optical design. The image quality of the system is evaluated, and the point diagram, distortion evaluation and tolerance analysis of the system are carried out to ensure the feasibility of the actual processing and assembly of the system. The system has a good reference and practical application value for the design of a miniaturized large field of view camera, and has a wide range of prospects.

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