Optical Design of Full View Lens based on Energy Luminance Analysis Chart of Stray Light

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Abstract

This paper presented optical design software (CODE V) in combination with stray light simulation software (Light Tools) to develop and analyze the influence of 360 degree lens stray light on MTF. We study the pupil entrance position of 2P3G lens group, set the pupil entrance position of the same inside-aperture lens which locates in the Lens 2(S2) or Lens 3(S1) surface. After simulation and analysis of ray tracing software, we get the best pupil entrance position of the lens to achieve the best efficiency and resolution. In addition, through the energy luminance analysis chart of stray light, comparison between this simulation and the actual test verifies that this design is consistent with the fact, so this method provides a reference for the future optical design and manufacture.

1. Introduction

The maximum angle of video camera is currently sold on the market with 300 degrees at most, and can not achieve 360 degree video range. This paper discusses the flare and ghost of 360 degree lens.

In optical system, the unneeded or additional derived light is known as stray light or ghosting, which will reduce the image quality and shelter the weak signal within the system. When the SNR signal is lower, the lens resolution will decrease. This paper uses optical design and simulation and analysis of ray tracing software to know the best pupil entrance position of the lens structure, and uses the energy luminance analysis chart of stray light to effectively correct the lens structure design to inhibit stray light. [1] [2]

2. Principle

2.1. Lens MTF Resolution

Generally, Modulation Transfer Function in short by MTF, this resolution takes lp/mm (Line-Pair per/mm, that is the number of black and white lines contained within each mm) as the unit to evaluate the lens resolution. Often, we use reverse projector or MTF machine to judge whether the lens resolution is good or bad. See Fig. 1 MTF projection resolution analysis map.

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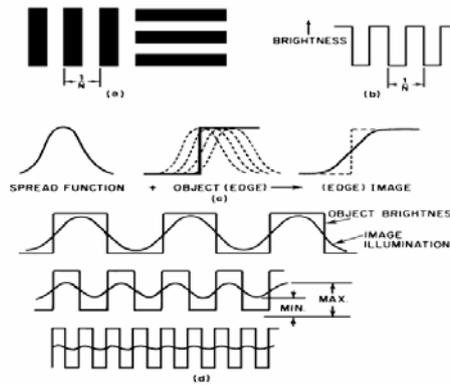
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Fig. 1 MTF projection resolution analysis map

2.2.　Concept of MTF Contrast

　　The MTF% equals to the ratio of the image contrast (I') to the object contrast (I) under a certain lp/mm (Frequency), as given in below.

$$MTF\% = \frac{I'_{max} - I'_{min}}{I_{max} - I_{min}} \ x \ 100\%$$

　　Contrast: Use 5 or 10 (lp/mm) to evaluate the contrast performance of the lens. With a small aperture, the MTF of a good lens at the frequency of 5 lp/mm should be 95% in the T and S direction; if lower than 90%, it is a poor quality image.

　　Sharpness: Use 40 (lp/mm) to evaluate the sharpness performance of the lens. 40 lp/mm mean that the lens can resolve a small object. Under this frequency, there is about 10% difference of MTF. Usually, traditional camera lens reaching 50% MTF at the frequency of 20 lp/mm can be regarded as a good lens.

2.3.　MTF Evaluation of CODE V

(1)　The maximum evaluation value of image is 1.

(2)　Representation method: 0.5 @ 200 lp (line pair) / mm.

(3)　Human eye can identify as long as MTF = 0.07

(4)　MTF is strongly related with the wavelength and the wavelength ratio.

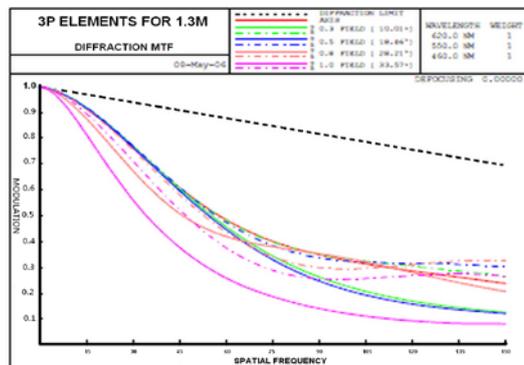(5)　Fig. 2 shows the difference MTF values at different space frequency. [3]

Fig. 2 CODE V MTF Diagram

2.4.　Lens Stray Light Analysis

　　Stray light is a harmful light which affects the image quality. It will increase the luminance of the dark part like the bright

part, thus reduce the imaging contrast and the MTF modulation transfer function; it is especially influential to the dark part. This reduces the entire lays of graphics, worsen the sharpness, decrease the color saturation, thus affecting the color balance, form a hazy feeling. Sometimes, even produce significant stray light spots and large block of ghosting [4].

In general, we can avoid flare of camera lens by following solutions include: (1) The lens edges are painted by black color. (2) The lens are been coated with Anti-reflective material. (3) Body parts are covered by black color. (4) The black plastic surface is treated with special material.

3. Research Method

Considering the optical angle, we use Light Tools software to carry simulation analysis. In order to identify the blind spot of the lens design, we reduce the process error and avoid procedure of development failure in procedure.

3.1. Process Analysis

Fig. 3 shows the Lens Flare verification flow chart, from confirmation of optical specifications to verification completion.
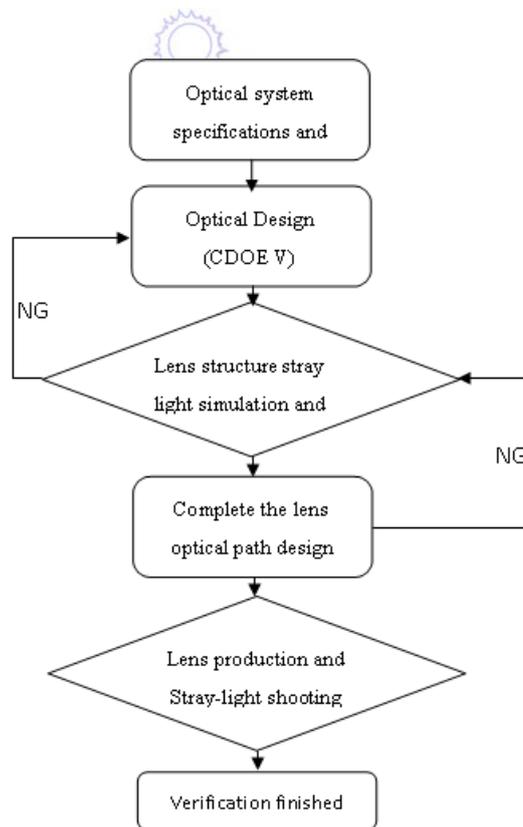

Fig. 3 Lens Flare Verification Flow Chart

3.2. Optical Design

Use the known lens module specifications, including structure of 3 glass lenses and two plastic lens structure to make non-spherical lens parameter setting based on the TTL and F/# values with CODE V optical design software, and finally make optimization. After calculation, we can get the best optical design values, as shown in Fig. 4, as well as the non-spherical coefficient of the lens, as shown in Fig. 5 [5] [6].

Fig. 4 Lens optical design parameters

Fig. 5 Optical non-spherical coefficient of the plastic lens

After optimization, the optical structure and optical path of the lens are as shown in Fig. 6, from which we can see the light route, the refraction of light when passing through the lens, and the imaging path, thus we can evaluate the lens structure, shape and location.
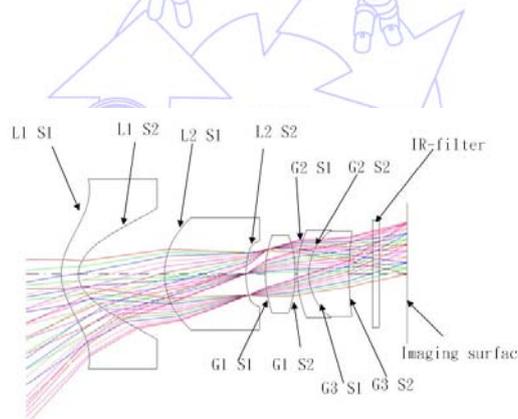

Fig. 6 Lens light patch diagram

In addition, through the lens MTF resolution produced by CODE V optical design software, we can see the Through focus quality of the lens MTF resolution, as shown in Fig. 7, and the MTF vs. Field performance as shown in Fig. 8. The lens astigmatism and distortion are shown in Fig. 9, and etc. lens optical specifications.
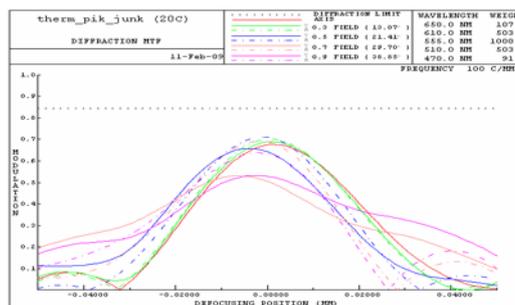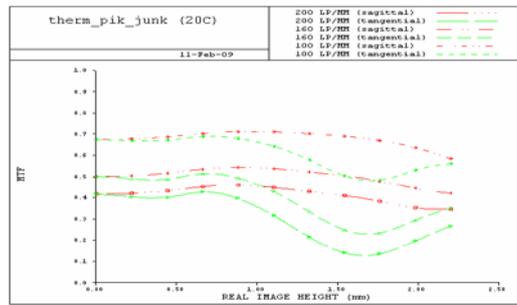

Fig. 7 Lens MTF Through focus
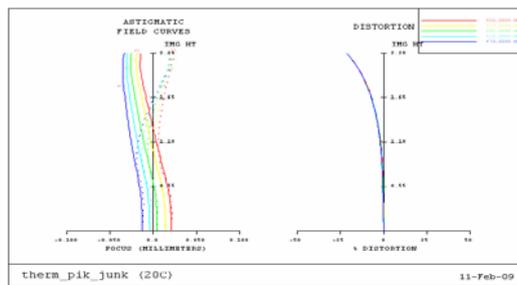
Fig. 8 Lens MTF VS Field Performance

Fig. 9 Lens Astigmatism and Distortion

3.3. Body Design

In light of the lens module specification requirements, design the internal structure and appearance of the lens. Use the preset lens shape as the starting value and boundary shape conditions to design the shape of the internal parts and the shape of internal lens, as shown in Figs. 10-11.
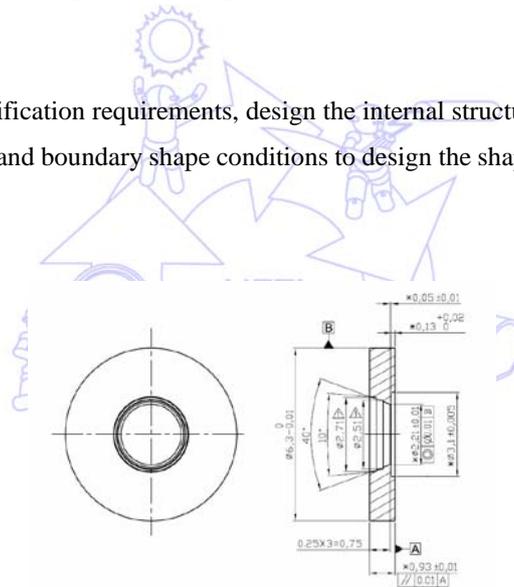

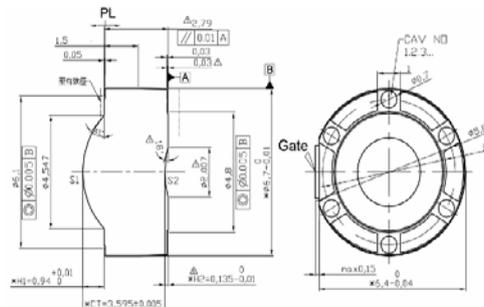
Fig. 10 Internal Body Parts

Fig. 11 Internal Lens Diagram

3.4. Light Tracing

Then use Light Tools to establish the lens components, as shown in Fig. 12, and make a simulation with Light Tools. Through analysis by Light Tools, you can more clearly understand the pupil entrance location (Stop). [7]
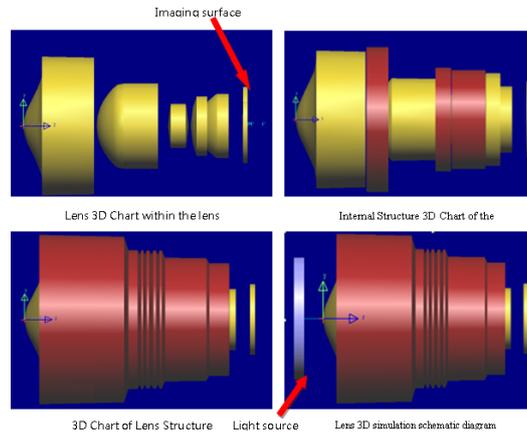
Fig. 12 3D Components Diagram established with Light Tools

As shown in Fig. 13, we can see the luminance distribution diagram from different angles when the   pupil entrance position (Stop) is different through simulation analysis of light trace diagram, as well as whether it will affect the MTF image quality.
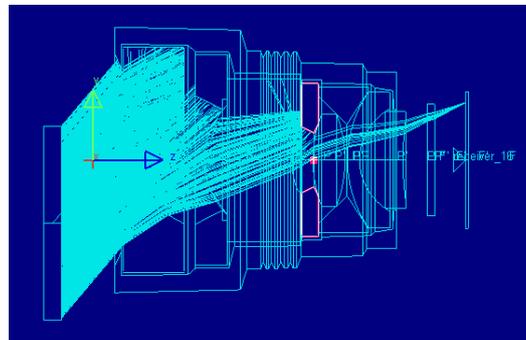
Fig. 13 Simulation of Light Trace Diagram from an Angle of 50 degrees

3.5. Lens Assembly

Assemble the related lens parts to confirm whether their sizes conform to the specification values, and according to the assembly diagram, as shown in Fig. 14. Next, put the single lens parts into the Barrel in sequence: first put the Glass 3 balsaming lens, then put Spacer 3 pads, after that respectively Glass 1, Spacer 2, Lens 2, Spacer 1 and Lens, and finally lock the Retainer to complete the lens assembly, as shown in Fig. 15

Fig. 14 Lens Assembly Diagram

Fig. 15 Finished Product of 360 degree Lens

4. Measurement Result

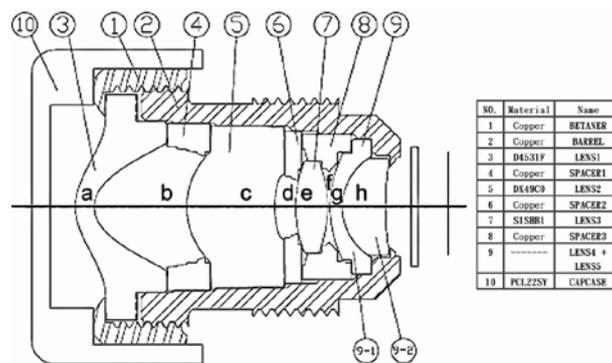Install the five camera lens module to shoot; therefore, we can confirm the actual resolution of the lens and whether there generates stray light, as given in Fig. 16. First, according to the single-lens resolution of Chart Photos will be conformed the quality based on MTF resolution in Fig. 17. Second, we can confirm whether there is stray light in an office environment as shown in Fig. 18. Finally, after both procedures are involved with and works normally, it can be confirmed the shooting effect of the whole lens module in Fig. 19. And that is the 360 degree shooting effect of this full view cameras module.
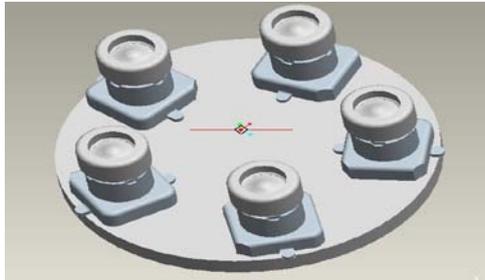

Fig. 16 Assembly of the Lens to Module

From Fig. 17 the Lens Shooting Confirmation Chart, it can be clearly seen that the resolution is good in the center and the surrounding, so this lens is judged as good.

Fig. 17 Resolution Confirmation of Lens Shooting Chart

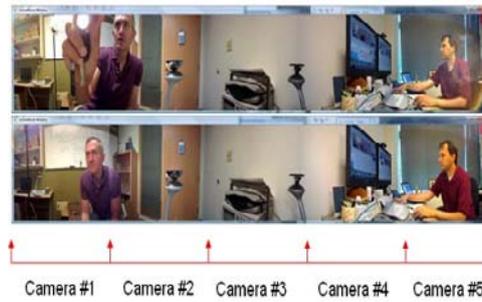Fig. 18 Stray light Confirmation in an Office Environment

Fig. 19 360-degrees Single-Lens Shooting Effect

S/N	Center	0.6 Field							
	TP0	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8
Spec	45	45	45	45	45	45	45	45	45
Averag	1	-1	1	3	2	5	4	2	3
Min	0	0	1	4	6	4	6	1	2
Max	1	-1	3	5	1	7	3	2	3

S/N	0.87 Field								EFL
	TP9	TP10	TP11	TP12	TP13	TP14	TP15	TP16	
Spec	37	37	37	37	37	37	37	37	
Averag	9	7	4	7	7	5	5	5	0.006
Min	10	12	6	9	8	7	6	5	0.001
Max	8	4	3	2	2	8	1	4	0.005

Fig. 20 Lens MTF measurement data average, difference between Min & Max values

5.   Conclusions

Through the simulation of stray light analysis software "Light Tools", and the actual measurement of lens MTF, it can be found that the pupil entrance position is on the Lens 3 in S1 surface. After testing this lens with MTF machine, it is found that compared to the lens structure applying Lens 2 in S2 surface, the MTF 0.6 Field is increased from 2% to 5%, and the outer 0.8 Field is even increased from 5% to 9%, as given in Fig. 20. A comparison between this simulation and the actual test verifies that this design is consistent with the fact, so this method provides a reference for the future optical design and manufacture, in order to reduce the development time and the waste of money, and to improve the development effectiveness.

References

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