Optimization design of periscope type 3X zoom lens design for a five megapixel cellphone camera

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ABSTRACT

This paper presents a periscope type 3X zoom lenses design for a five megapixel cellphone camera. The configuration of optical system uses the right angle prism in front of the zoom lenses to change the optical path rotated by a 90° angle resulting in the zoom lenses length of 6 mm. The zoom lenses can be embedded in mobile phone with a thickness of 6 mm. The zoom lenses have three groups with six elements. The half field of view is varied from 30° to 10.89°, the effective focal length is adjusted from 3.142 mm to 9.426 mm, and the F-number is changed from 2.8 to 5.13.

Keywords: periscope, zoom lens, cellphone camera, right angle prism

1. INTRODUCTION

Most of today's cell phone cameras are fixed focus lens. Because the fixed focus lens has the advantage of simple manufacturing and small volume. Optical zoom lens groups required for moving to change the focal length, and thus need more space, resulting in length is difficult to reduce. Periscope type zoom lens design used a right angle prism so that the optical path is folded to make the lens moving parts changed in the other direction. This can avoid the cellphone thickness increasing with increasing the length of the zoom lens. Gradually, such a manner is being applied in the cellphone, the zoom lens can be hidden in the phone. J. H. Chang [1] designed the periscope four groups 3X Zoom mobile phone camera with five million-pixel, the focal length of 4.75 mm to 14.25 mm, F / # of 3.5 to 6.8, wide viewing angle of 61.7 to 23.7, lens length of 28 mm, lens thickness of 9 mm. The relative illumination is 50 to 85%, and optical distortion is -4.5% to 1.0%. S. C. Chia [2] designed periscope type 2.55X zoom lens with three groups, which composed of a right-angle Prism and six lenses, lens thickness of 8.23 mm, lens length of 35.83 mm. In 2008, S. C. Park [3] designed a periscope four groups 2.9X zoom lens, which does not require a lens in front of the right angle prism, the lens thickness of 7 mm, the lens length of 37.56 mm. And Park in 2009 [4] made four groups periscope-type 5X zoom lens, the lens thickness of 8 mm, length of the lens is 40 mm. In 2013, Park [5] made four groups periscope-type 10X zoom lens, the lens thickness of 12 mm, length of the lens is 53 mm

2.Theory

At first, the focal length of the entire system was determined by the sensor size, and then other quality and design requirements were developed.

2.1 Sensor Specifications

The OmniVision 5 megapixel CMOS sensor was chosen as an image detector combined with zoom lenses optimization design. The specification of the CMOS sensor is given in Table 1.

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Table 1. Sensor specification

Item	Specification
Model	OV 5670
Sensor Type	CMOS
Resolution	2592 × 1944
Device Diagonal	1/5"
Active Area	2.903 mm × 2.177 mm
Pixel Pitch	2.2 μm

2.2 First order design

A piece of IR-cut filter was used in front of an image sensor, its function as a filtering an infrared light to avoid entering the imaging plane. Each aperture value (F-number) of the zoom lenses configuration was in the range of 2.8 to 5.13. The zoom lenses have three lens groups, and the lenses are composed of two pieces of glass lenses (namely 2G) and three-piece plastic lenses (namely 3P). The lens surface form composed of four spherical surfaces (S) and six aspherical surfaces (ASP). The thickness of the zoom lenses is 6 mm and the lenses length (the distance from prism apex to the image plane) is 26.65 mm. Because a right angle prism with side length of 6 mm was arranged in front of the zoom lenses, the clear aperture must be less than 6 mm for the design of each lens. The above preliminary specifications are re-organized as listed in Table 2.

Table 2. Lens specification

Item	Specification
Image height	1.8143 mm
Half field of view	30°~10.89°
Effective focal length	3.142 mm~9.426 mm
F/#	F/2.8~F/5.13
Lens group number	3 groups
Lens configuration	2G3P
Surface form	4S and 6ASP
Lens clear aperture	< 6 mm
lenses length	26.65 mm
Zoom ratio	3:1

Lens design is considered in the visible spectrum (we take five visible wavelengths, wherein the third wavelength is dominant wavelength), the wavelength weighting is determined by the daytime visual sense of the human eye, as listed in Table 3.

Table 3. Wavelength and weighting

Wavelength	Weighting
642.73 nm	7
590.86 nm	36
542.02 nm	42
500.48 nm	13
465.61 nm	2

Taking into account the lens manufacture can be processed. Some specifications are used in the industry, for example the lens thickness requirements. The lens material can be divided into glass and plastic, and its specification is shown in Table 4.

Table 4. Lens manufacture requirement

Glass lens	
Center thickness	> 0.7 mm
Edge thickness	> 0.8 mm
Air spacing	> 0.1 mm
F/#	F/2.8~F/5.13
Plastic lens	
Thickness ratio	3.5:1
Center thickness	> 0.7 mm
Edge thickness	> 0.5 mm
Air spacing	> 0.1 mm

3. DESIGN RESULTS

3.1. Configuration of zoom lens

After optimization of the zoom lens, the lens diagram at different focal lengths is shown in Figure 1. The first one is a right angle prism. The second, fourth and fifth components are aspherical lens. The third and sixth components are spherical lens. The last two components are flat glass, the first is for the IR cut filter, the last is a cover glass for the sensor.

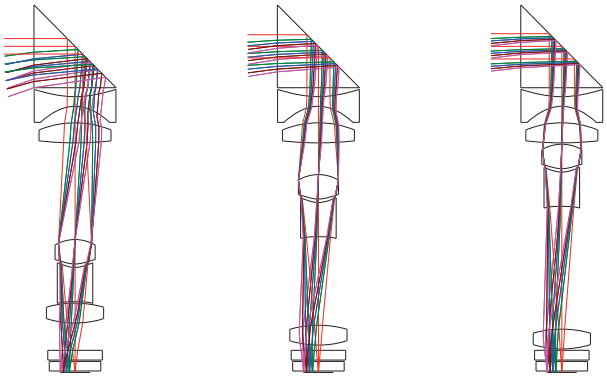
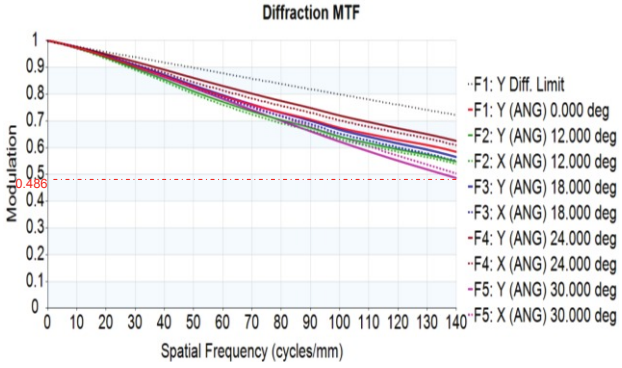


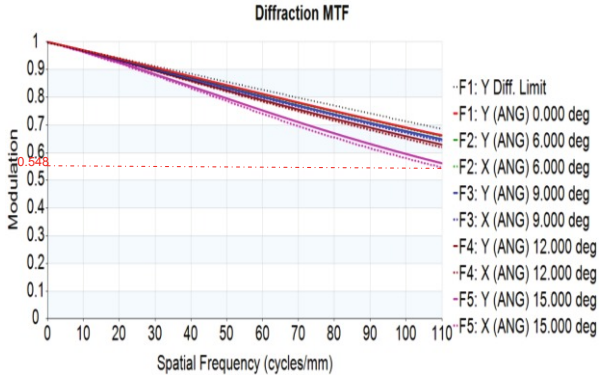
Fig. 1. Configuration of zoom lens with different focal lengths. (a) f= 3.142 mm；(b) f= 6.770 mm；(c) f= 9.426 mm.

3.2 Image quality of zoom lens

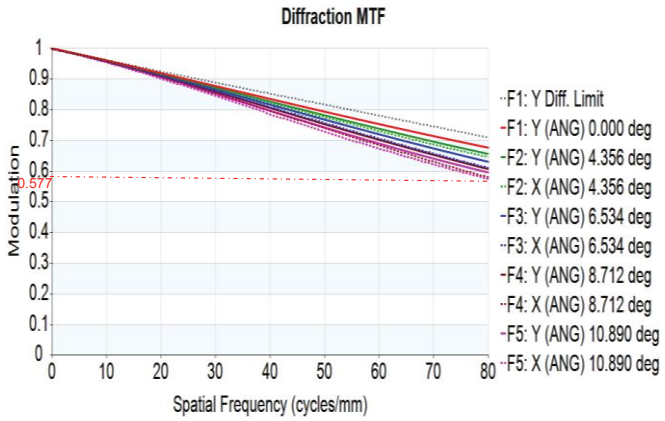
Because the right-angle prism with an optical axis turning 90 degree, prismatic side length of 6 mm is equal to the lens thickness. The imaging performance of the optimized zoom lens is evaluated. Figure 2 shows the MTF performance plot for the optimized zoom lenses at different focal lengths and all field of viewing angles, respectively. In the MTF diagram, Y is representative of the tangential (Tangential), while X is representative of the radial (Sagittal). The MTF minimum value of 0.486 occurs at f = 3.142 mm and FOV=1.0. Calculating the difference absolute value between tangential and radial MTF, the maximum value of 2.5% occurs at f = 9.426 mm and FOV=0.8.



(a)



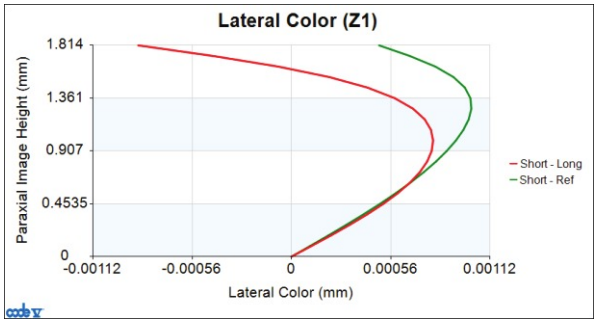
(b)



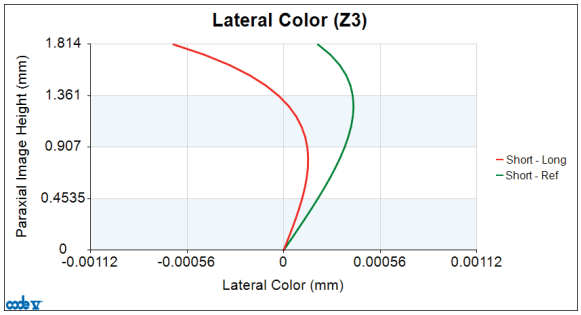
(c)

Fig. 2. The MTF curves of zoom lens at different focal lengths (a) f= 3.142 mm;(b) f= 6.770 mm;(c) f= 9.426 mm.

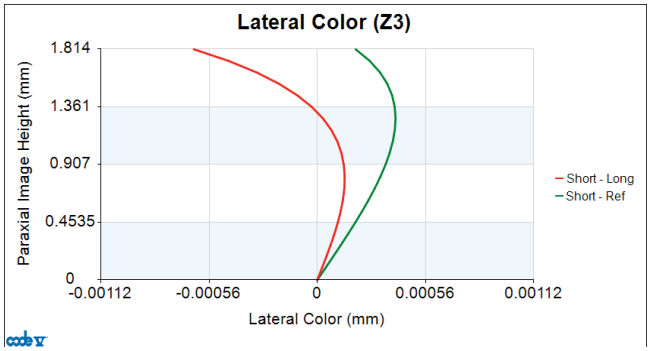
Figure 3 shows the lateral color of zoom lens after optimization processed under different focal lengths and in all fields of view.



(a)



(b)



(c)

Fig. 3. Lateral color curves of zoom lens at different focal lengths (a) f= 3.142 mm ; (b) f= 6.770 mm ; (c) f= 9.426 mm.

Figure 5 shows the relative illumination of the optimized zoom lenses at different focal lengths and all the field viewing angles. A minimum value of 67.60% for the relative illumination occurs at f = 3.142 mm and FOV=1.0.

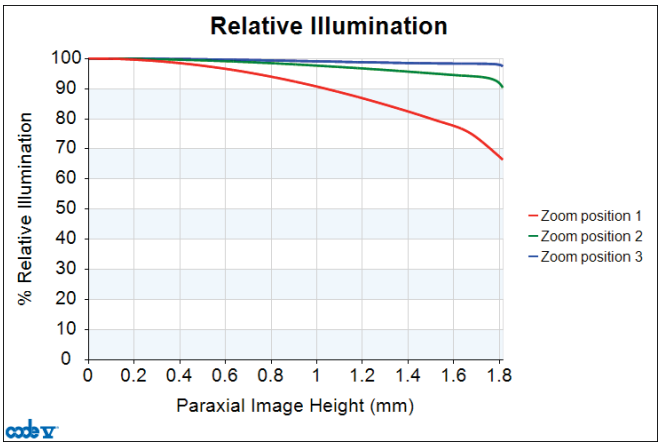


Fig. 4. Relative illumination versus image height plot.

The zooming control method of the zoom lenses is using a stepper motor associated with a screw structure of the lens barrel to control lens-group movement. A zooming trajectory is described the moving path of the zoom lens group by the spiral structure of the lens barrel, in order to avoid the air spacing of lens groups is too small during zooming. The optimized zoom lenses must draw a zooming trajectory to determine whether the trajectory of the zoom lens overlap between the different lens groups to facilitate the production of the zoom lenses. The distance between the front and the rear vertex to the image plane was plotted a zooming trajectory for the three lens groups, as shown in Fig. 5. Air spacing between each lens group are greater than 0.1 mm.

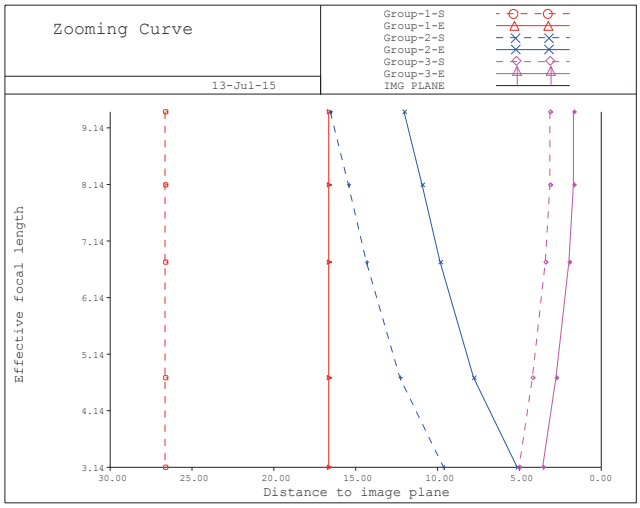


Fig.5. A zooming trajectory

4. CONCLUSION

This work has been presented an optical design of periscope type 3X zoom lenses associated with five million pixel mobile phone camera. The specifications of the zoom lenses include the lens length of 26.65 mm, the lens thickness of 6 mm, a focal length range of 3.142 mm to 9.426 mm, half- FOV of 30° to 10.89°, F / # of 2.8 to 5.13. The number of lens group was three groups with five lenses and a right-angle prism. For the image quality of the proposed zoom lenses, the design results reveal MTF > 48.6 %, | TMTF-SMTF | < 10 %, | Lateral color | < 1.019 μm, | Optical distortion | < 1 %, | TV distortion | < 0.79 %, and relative illumination > 67.6 %.

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