Miniature Camera Lens Design with a Freeform Surface

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Abstract: We present a miniature camera lens design using a freeform surface based on the pedal curve to the ellipse and compare its optical performance to the conventional design with a standard even aspheric surface.
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1. Introduction

Camera lens designs for mobile platform electronics applications such as cell phones and tablets have been rapidly developed in the past decade. Although these miniature cameras in mobile devices are becoming ubiquitous in our daily lives, better optical performance is always demanded. To achieve good optical performance for the miniature cameras, aspherical surfaces are extensively used during the lens design. However, the performance of the miniature cameras designed with conventional aspherical surfaces is approaching a limit. While lens designers are still pushing the limits of their designs with conventional even/odd aspherical surfaces, a more efficient surface description is desirable for improvement. A recently published paper [1] introduced a freeform surface that combines base surfaces of the pedal curve to the ellipse for light illumination control. In this summary, we discuss the benefits of using such as pedal curve and its freeform combination for miniature camera lens optimization. Section 2 briefly explains some design challenges of miniature camera lenses. Section 3 shows how we set up a benchmark lens from an existing patent. Section 4 explains the use of the pedal curve to the ellipse on miniature camera design. In Section 5 the evaluation design we optimized is compared with the benchmark lens.

2. Challenges of miniature camera lenses

Lens designers face challenges when designing miniature camera lenses compared to conventional large scale camera lenses. The most limiting specification is the package size. In order to avoid color crosstalk on the digital sensor, the image space chief ray angle (CRA) is limited, usually no more than 30 degrees [2]. The stop aperture must be located close to the first surface to fulfil the CRA requirement, which cause the lens not to be symmetric about the stop. The lack of symmetry about the stop makes correcting distortion and lateral color difficult. In order to efficiently correct aberrations, aspherical surfaces are used extensively with injection molding of plastic. The limited choice on plastic materials also makes correcting axial color challenging. Due to the demand of low-light performance of the miniature cameras, larger aperture lenses with lower F/# are desired. More lens elements may be needed and this makes it difficult to maintain the total track length (TTL). However, mobile devices are becoming thinner at the same time, which causes the lens to protrude over the surface of some mobile devices. The relative illumination (RI) is often required to maintain at least 50% at the sensor corners [3]. Nevertheless, there is a tradeoff between relative illumination and aberration control during the lens optimization.

3. Benchmark lens

The starting point of our benchmark lens design is from the first embodiment in U.S. Patent 9,110,270. The patent lens contains five lens elements with an IR filter in front of the sensor. The lens is re-optimized into our benchmark lens using only conventional even aspherical surfaces with the design specifications provided in Table 1. The number of aspheric coefficients for each surface remains the same in the patent specification.

Table 1. Design specifications for benchmark lens and evaluation lens

Wavelength	*f* [mm]	F/#	FOV [deg]	TTL [mm]	Distortion	Edge RI
F, d, C	4.1	2.2	69.8	<5.2	<1%	>50%

4. Evaluation Lens

The rear group of miniature camera lenses usually contains one or two elements that are strongly aspheric to correct field curvature, astigmatism and distortion [4]. The shape of these elements cannot be easily explained as the aspheres become dominant at large field angles [2]. However, these lens elements often contain surfaces with different curvature direction between the center of the surface and the edge (e.g., concave in the center and turning back to convex before the edge). It is noted that this surface profile can be described by the pedal curve to the ellipse. The sag S(r) of this pedal surface is obtained by rotation about z-axis

$$S(r) = b - \sqrt{\frac{b^2 - 2r^2 + \sqrt{b^4 + 4(a^2 - b^2)r^2}}{2}}\,, \qquad (1)$$

where a is the major axis of the ellipse, b is the minor axis, and r is the radial distance from the optical axis. A freeform polynomial surface [1] can be written as

$$z_p(r) = A_1S_1(r) + A_2S_1^2(r) + A_3S_1^3(r) + B_1S_1(r) + B_2S_1^2(r) + B_3S_1^3(r), \qquad (2)$$

where $S_1(r)$ and $S_2(r)$ are two sets of pedal surfaces, $A_1 - A_3$ and B_1-B_3 are coefficients. Our design used the freeform surface to replace surface 7, surface 9, and 10 of the benchmark lens.

5. Lens comparison

The layouts and the optical path difference (OPD) plots of both benchmark and evaluation lenses are shown in Fig.1. The freeform surfaces are marked on the evaluation lens. Most layout differences come from the rear group. Package sizes remains the same for both lenses. For the aberration control, OPD are evaluated at over 4 equal-area fields. The evaluation lens shows more uniform performance over the field of view, while the OPD performance downgrade significantly at larger field of view for the benchmark lens. Such downgrade in performance at large field of view can be also observed from the MTF plot in Fig.2. The evaluation lens shows more uniform contrast performance over the field.

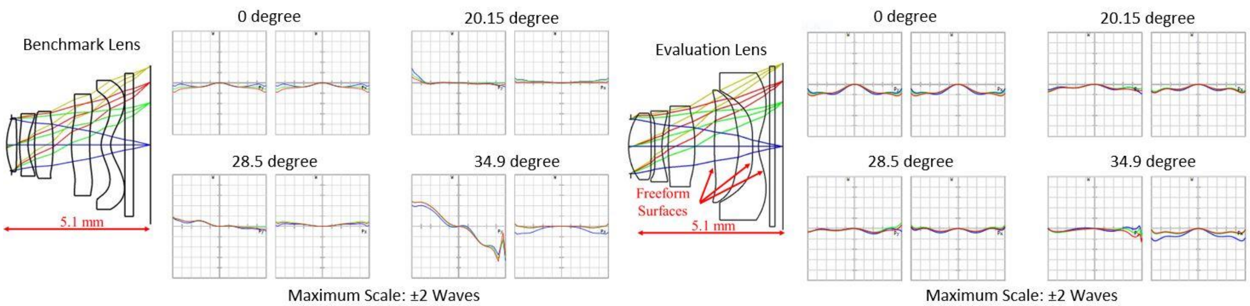

Fig.1. Lens layout and OPD plots for the benchmark lens (left) and the evaluation lens (right)

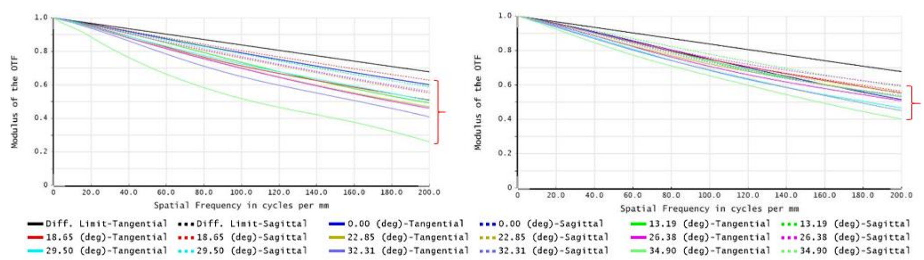

Fig.2. MTF plots for the benchmark lens (left) and the evaluation lens (right), the red brackets show the contrast distribution over the field

6. Conclusion

We briefly discussed our research about miniature camera lens optimization using surfaces based on the pedal curve to the ellipse. Our evaluation lens shows better aberration control at large fields of view and uniform contrast distribution at high spatial frequencies. In addition, the number of parameters to describe the pedal surfaces is decreased as compared to the benchmark design. Overall, we show that freeform surfaces based on the pedal curve to the ellipse might be useful in imaging lens design.

7. References

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