Impact of Lens Chief Ray Angle on Image Quality

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1. Introduction

Lens chief ray angle refers to the angle of incidence of an off-axis ray passing through the center of the lens stop on the image plane. If the imaging medium is a silver-halide film, the chief ray angle would not make too much difference to the final image quality because the film grain has isotropic angular response. However, if the imaging medium is a CCD or CMOS imager, the lens chief ray has significant impact on the final image quality. This is because the basic imaging element (a pixel) of CCD/CMOS imagers does not have isotropic response. This paper exams the effect of lens chief ray angle on the overall image quality.

2. Experiment

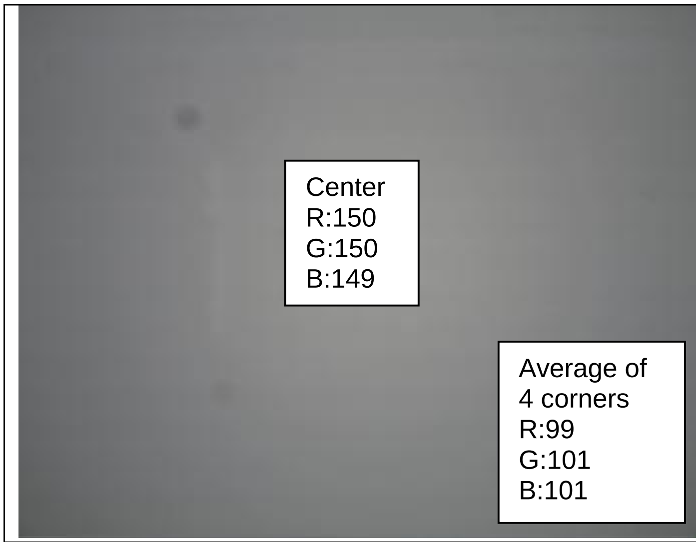
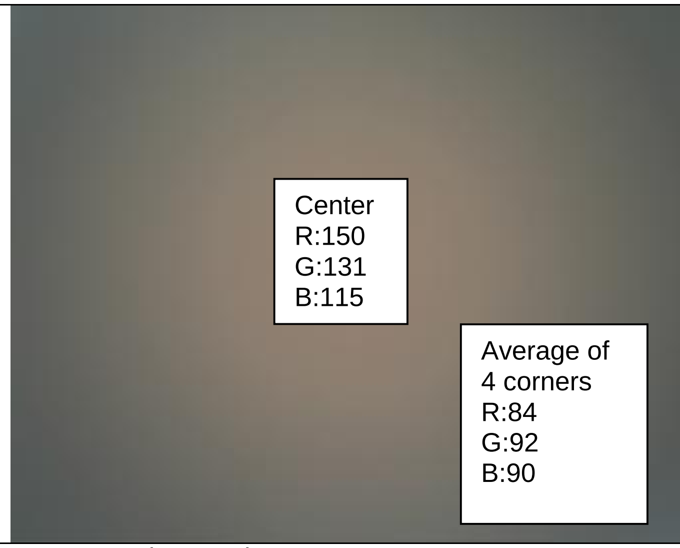
The Micron MT9D011 imager is used with two different lenses: Sunex PN DSL746 with a 1G2P structure and a competitor lens (also a 1G2P lens). Two lenses have the same f-stop of 2.8. The Sunex lens is designed to limit the max. chief ray angle within 20 degrees at the corner of the imager. The max. chief ray angle of the competitor lens is 25 degrees. An uniform white background is captured by using both lenses. The result is shown as follows.

Sunex DSL746	Competitor Lens
	

As can be seen from the above figure, the DSL746 lens has more uniform response in terms of color and corner brightness. The ratio of corner brightness to the center is known as “relative illumination”. It is also clear that the white balance (ratios between G, B and R) is more consistent from center to the corner with DSL746 lens. This difference can be explained in terms of chief ray angle mis-match with the sensor. At off-axis field angles, the higher chief ray angle of the competitor lens is outside the peak response region of pixel micro-lens. This results in a reduction in the overall response at off-axis angles. With color imager the higher chief ray angle can also cause cross-talk between adjacent pixels of different color. The cross-talk causes the ratios between R, G and B to vary from center to corners. A typical result is that the center will tend to be warmer, and corners cooler, as shown in the above figure.

3. Relative Illumination and Relative Color

The above described phenomenon can be measured using many commercially available programs such as PhotoShop and Jasc Paint Shop Pro. We would first read out the pixel values for each R, G and B channel in the center of the image. These values will be used as baseline numbers. We will then read out the R, G and B pixel values at each of the four corners. Relative illumination (RI) can be computed as the ratio of corner luminance Y (=0.3*R+0.59*G+0.11*B) to the center luminance. The white balance is represented by the ratio of R to B. If R/B >1, the image is warm. If R/B<1, the image is cool. Relative color (RC) is represented by the corner R/B ratio divided by the center R/B ratio.

 	
Center-R/B=150/149=100.6% Corner-R/B=99/101=98% **Relative Color(RC)=(Corner-R/B)/(Center-R/B)=97.4%** Center Y=0.3*R+0.59*G+0.11*B=149.89 Corner Y=0.3*R+0.59*G+0.11*B=100.4 **Relative illumination (RI) = 67%**	Center-R/B=150/115=130.4% Corner-R/B=99/101=93.3% **Relative Color(RC)=(Corner-R/B)/(Center-R/B)=71.6%** Center Y=0.3*R+0.59*G+0.11*B=134.94 Corner Y=0.3*R+0.59*G+0.11*B=89.38 **Relative illumination (RI) = 66%**

4. Conclusion

Mobile imaging modules demand very short profile lenses. The short profile lenses tend to have very high chief ray angles. The high chief ray angle can be detrimental to the image quality given the limited angular acceptance of the micro-lens array on the imager. This paper demonstrates that a 5 deg difference in the chief ray angle can cause a significant relative color issue (only 71.6% of the ideal goal) on the Micron 1.3MP imager. An acceptable relative color value should be >95% but less than 105% for a good imaging system.