

Characterization of variable colour effects in ISET lens model

To identify the severity of the colour distortion in current devices, we first investigated the problem in the ISET environment. An advanced lens model was used that contained wavelength-dependent effects (both blurring and photon loss). The script that generates this advanced lens model is included in the appendix.

While wavelength-dependent effects were included in this model, position-dependent were not. As such, position-dependent effects were produced by running the lens model with 3 different distortion factors: low distortion (image centre), medium distortion and high distortion (image periphery).



Figure 1: Macbeth scene under low lens distortion. This image was used to represent the center of the image where distortion would be small.



Figure 2: Macbeth scene under medium lens distortion.



Figure 3: Macbeth scene under high lens distortion. This image was used to represent the periphery of the image where distortion would be high.

ISET was then used to find the colour balancing matrices required to restore the correct colours for the Macbeth colour charts. The results are shown below for both a pixel size of 2.8um and 1.4um.

	2.8um pixel	1.4um pixel
distortion factor: 0.1	$\begin{bmatrix} 1.1682 & -0.1303 & 0.0567 \\ 0.3650 & 2.1970 & -0.7279 \\ -0.7548 & -0.1218 & 2.8389 \end{bmatrix}$	$\begin{bmatrix} 4.7358 & -0.5182 & 0.2771 \\ 1.3670 & 8.8330 & -3.0706 \\ -2.9032 & -0.4106 & 11.5262 \end{bmatrix}$
distortion factor: 0.5	$\begin{bmatrix} 1.1689 & -0.1643 & 0.0522 \\ 0.4715 & 2.2928 & -0.7631 \\ -0.9219 & -0.1901 & 2.8620 \end{bmatrix}$	$\begin{bmatrix} 4.6685 & -0.5225 & 0.2345 \\ 1.4450 & 8.7212 & -3.0017 \\ -2.9777 & -0.4596 & 11.3499 \end{bmatrix}$
distortion factor: 1.0	$\begin{bmatrix} 1.1754 & -0.1297 & 0.0590 \\ 0.3592 & 2.2044 & -0.7352 \\ -0.7281 & -0.1076 & 2.8886 \end{bmatrix}$	$\begin{bmatrix} 4.6502 & -0.6035 & 0.2135 \\ 1.7739 & 8.8671 & -3.0773 \\ -3.5109 & -0.6209 & 11.3460 \end{bmatrix}$

At first glance, the matrices look very similar. The matrix coefficients themselves do not vary greatly. For example, the main diagonal values change by less than 2% in all cases.

While the matrices do not seem to change much, a quantitative way of analyzing the colour balancing differences is required. As such, we applied the matrices for a distortion factor of 0.1 and 1.0 to a range of colours and observed the resulting

delta E changes. The colours were randomly sampled, and the results are shown below. A white point XYZ of [95.0399,100,108.8932] was used.

Colour (RGB)	Delta E of Colour-Balanced RGB
100,40,30	44.4253
100,200,50	30.1294
40,70,55	12.4634
10,10,10	8.0201
30,150,200	1.5541
200,150,50	1.4969

There are several important findings in these results:

- The differences in the colour balancing matrices are significant enough that they can sometimes cause visually perceivable colour changes. (Delta E of 5 or greater is assumed to be visually perceivable).
- Using a smaller pixel size makes the problem worse, but not by a significant amount (changes matrix values are still limited by 2%).
- The distortion is NOT linear. Some of the values of the matrices for the medium blur factor are higher or lower than the values for both the other matrices.

To further determine what is actually happening in the colours, we sampled the SPD at the centre of the white block in the Macbeth colour chart. The results are shown in figure 4 below.

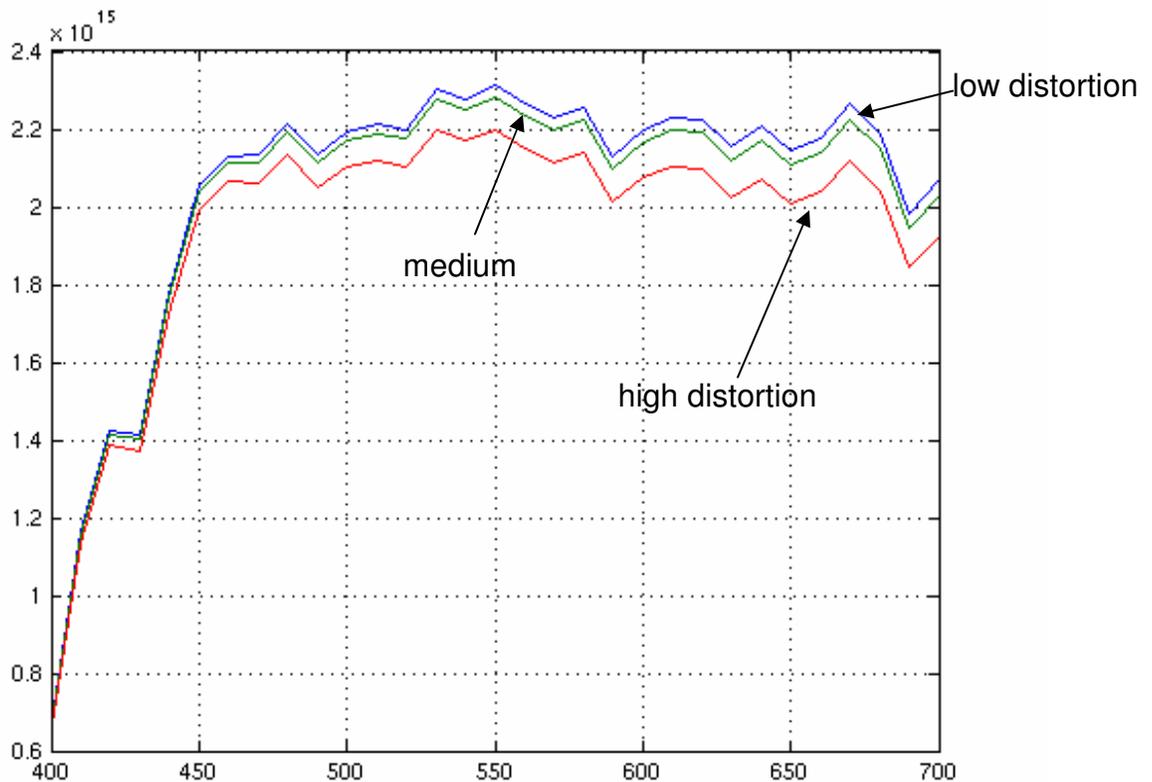


Figure 4: SPD of white block in Macbeth colour chart under low (blue line), medium (green line) and high (red line) distortion

From this SPD we can see that there actually is a colour change. This is because there is a wavelength-dependent photon loss which is changing the shape of the SPD. Note that the SPD gap is widening as wavelength increases.

Thus, there are two visible effects caused by the lens

- Color blending at boundaries due to blurring
 - This cannot be corrected by colour balancing. Colour balancing cannot unblend the colours.
- Photon loss caused by the lens model (wavelength-dependent)
 - Causes true colour change

In summary, variations in colour balancing matrices exist, but these variations only sometimes result in visible changes. Even in the worst cases of a delta E of approximately 50, the colour change is not drastic. The question then becomes: are the changes pronounced enough to warrant use of a variable colour balancing matrix? In the end, there is a tradeoff: true colour accuracy vs processing time/effort.