Color Reproduction in LED Virtual Production Stages

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Motivation

Virtual production stages make use of LED displays with RGB primaries, film lighting equipment, and digital cameras. In such a studio, color reproduction can be divided into two categories:

1. Reproducing object colors in the physical scene

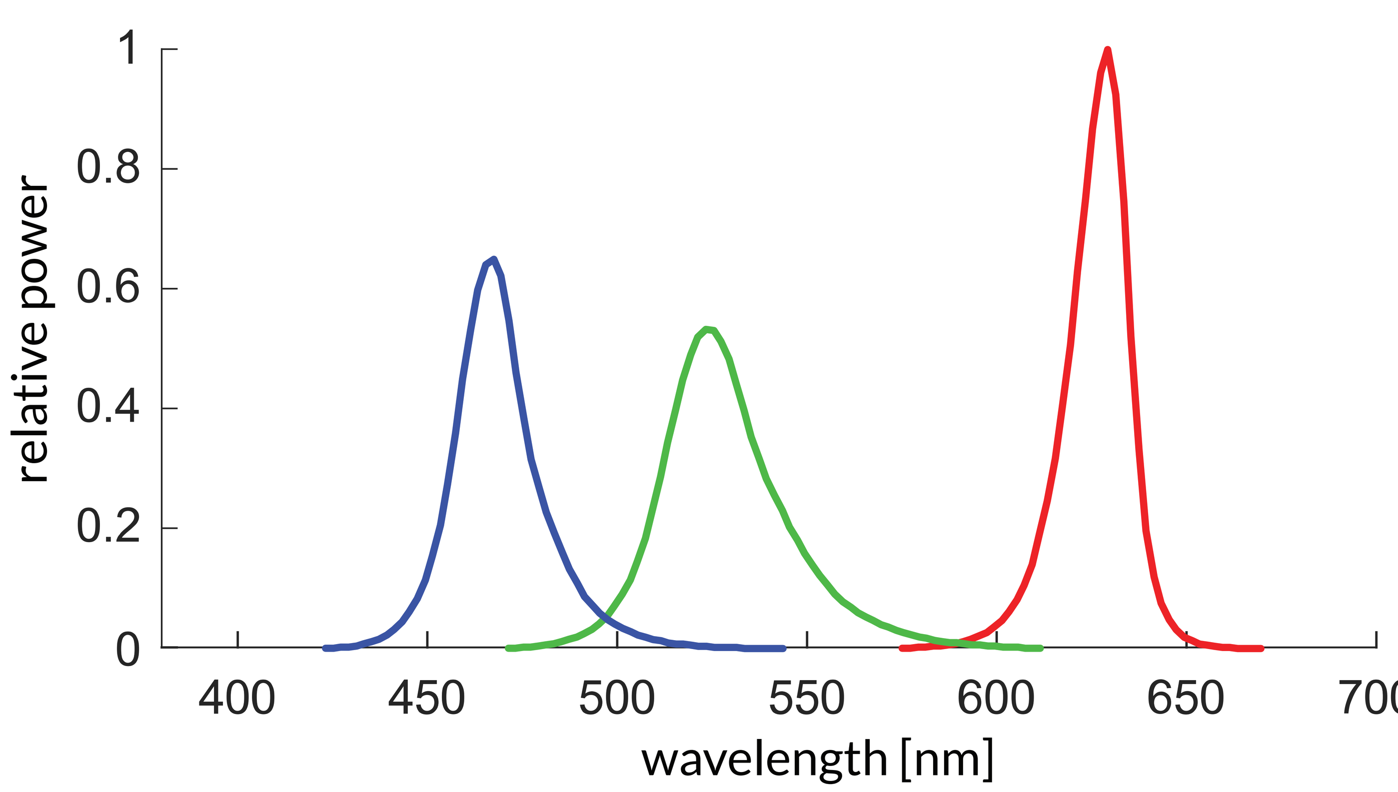


Fig. 1: Spectrum of a ROE Ruby LED display

The spectrum of an LED display contains large gaps and renders objects in an unnatural manner. Other film lighting equipment does not exhibit the same issues, making colors inconsistent when both are used.

2. Calibrating the display to the camera observer
LED displays come factory calibrated for a human observer. Because cameras are not colorimetric, a device specific calibration is required.

Contributions

- We improve object color accuracy over previous works by using a non-linear color correction method with root polynomials [1]
- We jointly optimize the spectrum of additional light sources together with the color correction for more consistent colors
- We propose an approximate inverse of the root polynomial method to calibrate the display

[1] G. D. Finlayson et al., "Color Correction Using Root-Polynomial Regression", (2015)

Method

1. Reproducing object colors in the physical scene
We use spectral measurements of the display, a multi-channel LED light source, the camera sensitivity, and object reflectances to simulate camera responses.

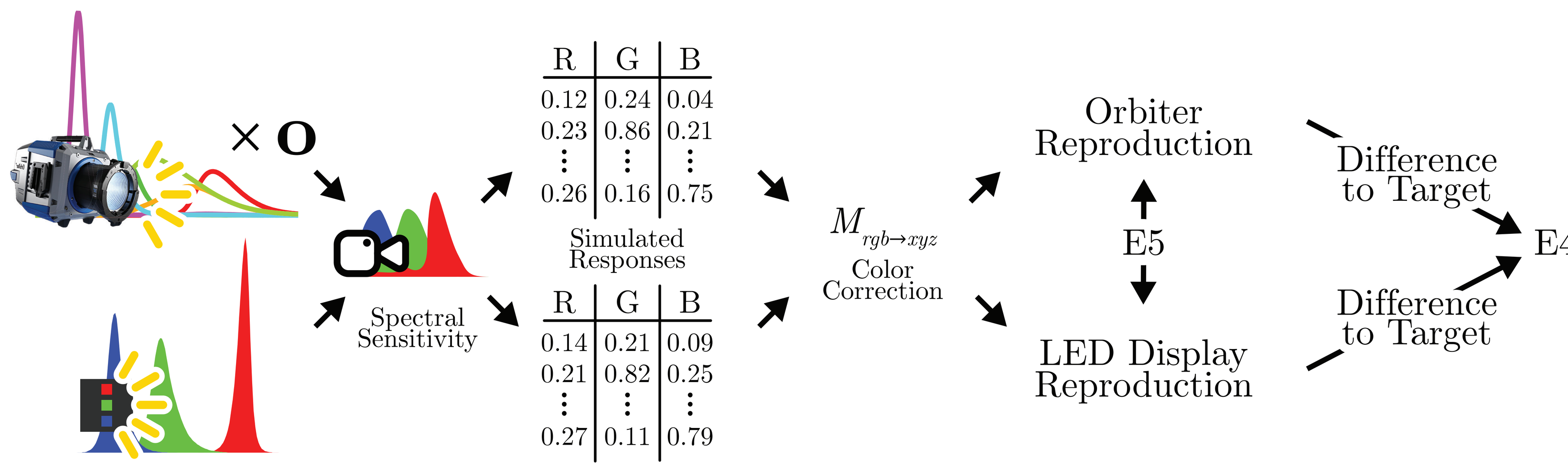


Fig. 2: The architecture of the joint optimization

By minimizing a loss function (eq. 1), we jointly optimize the color correction matrix $M_{rgb\to xyz}$ and the multi-channel illuminant configuration $\mathbf{o}$.

$$\{M_{rgb\to xyz}, \mathbf{o}\} = \underset{M_{rgb\to xyz},\, \mathbf{o}}{\arg\min} \sqrt{\omega\,(\Delta_{E4})^2 + (1-\omega)(\Delta_{E5})^2} \qquad (1)$$

We constrain the optimization:

- The color of the multi-channel illuminant must exactly match the LED display
- The color correction must preserve the white balance of the camera

2. Calibrating the display to the camera observer
A linear matrix $M_{disp\to obs}$ is obtained which predicts the camera's response to a display signal. We then pre-process the display signal $\mathbf{v}^{XYZ}_{lin}$:

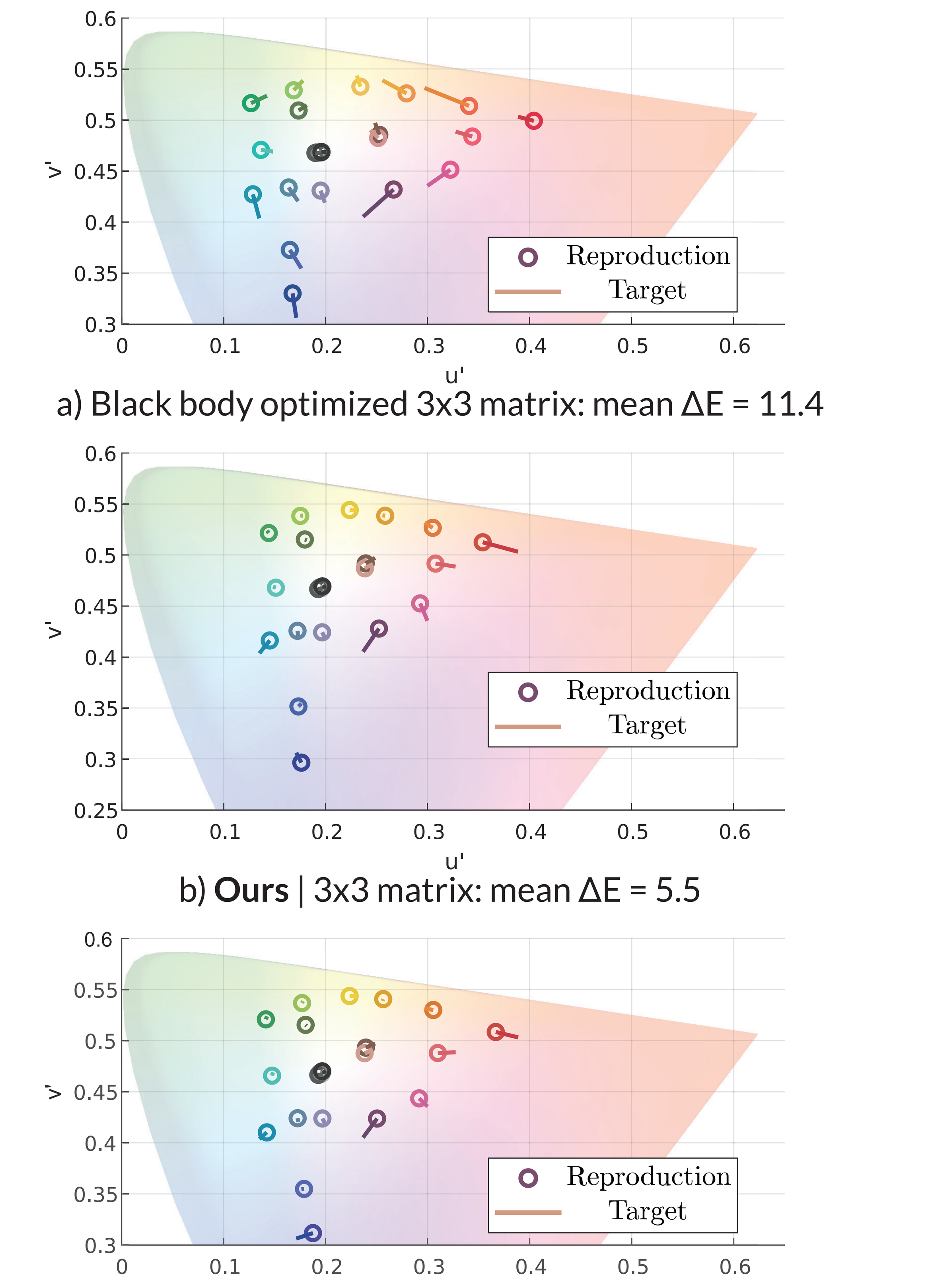
$$\mathbf{v} = \mathrm{EOTF}^{-1}(M^{-1}_{disp\to obs}\,\mathrm{diag}(\mathbf{wb})^{-1} M^{-1}_{rgb\to xyz}\,\mathbf{v}^{XYZ}_{lin}) \qquad (2)$$

The equation above uses the inverse of the color correction $M^{-1}_{rgb\to xyz}$ which was previously optimized in step 1.

An exact inverse of the 3x13 root polynomial matrix cannot be computed. We therefore propose finding another root polynomial matrix by regression which approximates the inverse.

Experimental results

1. Reproducing object colors in the physical scene
The results for ColorChecker patches in Figure 3 show that our method significantly improves color rendition by an average ΔE of 6.7



a) Black body optimized 3x3 matrix: mean ΔE = 11.4

b) **Ours** | 3x3 matrix: mean ΔE = 5.5

c) **Ours** | Root polynomial 3x13 matrix: mean ΔE = 4.7

Fig. 3: u'v' chromaticity diagrams showing the measured reprduction of ColorChecker Classic patches (○) and the targets under a refence illuminant (—)

2. Calibrating the display to the camera observer
We recorded a test signal and plotted the color errors below. The reproduced colors are close to their targets.