Robust Content-Dependent Photometric Projector Compensation

Presentation for Procams 2006 workshop on projector-camera systems

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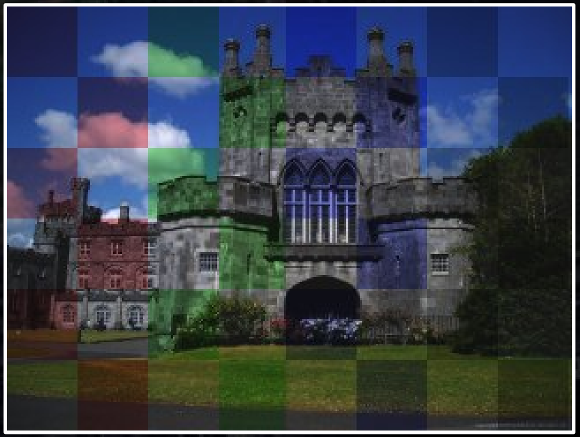
Motivation

- Cheap and portable projectors will be used in non-ideal situations
  - Surface reflectance makes patterns
  - Ambient light reduces contrast
- We want to be robust to difficult projection situations

original



patterned surface

ambient light

Goal

- Compensate for irregularities in the projection system
- Achieve contrast and saturation as close as possible to that in the ideal condition

uncompensated result

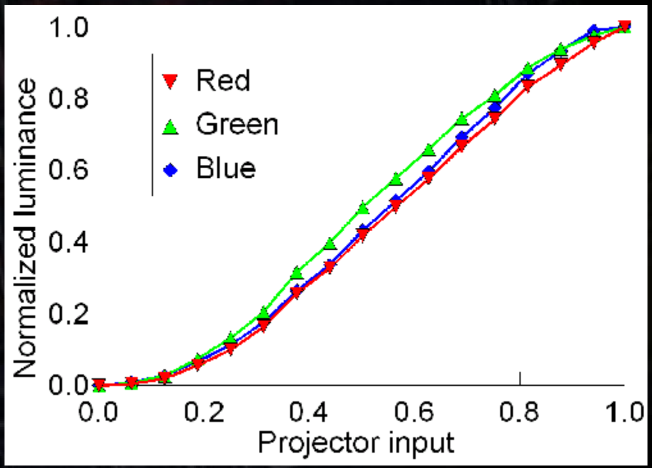
compensated result

Overview

- Characterizing the projection system
- Fit the image to the display
  - Image fitting
  - Framework
  - Our implementation
- Results
- Future work

Characterization

- Assumptions
  - Environment is static
  - Surface is Lambertian
  - Three additive primaries
- Linearize projector response



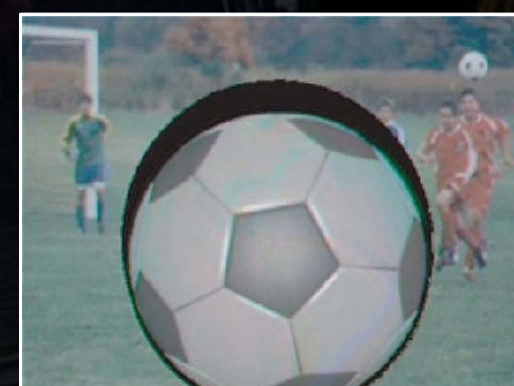
Characterization

- Get radiometric model that defines a per-pixel mapping RGB to XYZ

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet \end{bmatrix} \begin{bmatrix} R \\ G \\ B \\ 1 \end{bmatrix}$$

surface

uncompensated result

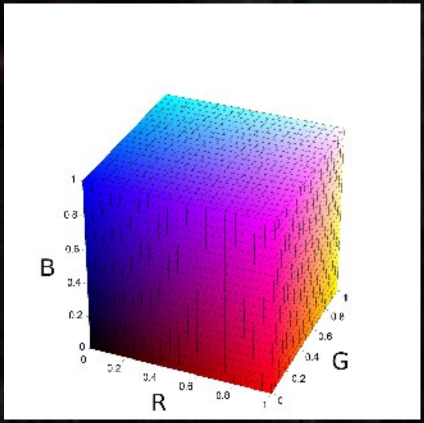


compensated result

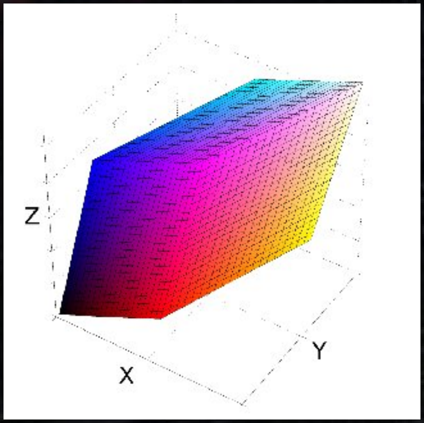
Grossberg, Peri, Nayar, and Belhumer, *Making One Object Look Like Another: Controlling Appearance Using a Projector-Camera System*, CVPR 2004

Characterization

- RGB input is limited to unit cube
- This corresponds to a gamut in XYZ space
- Gamut is different at every display pixel



RGB



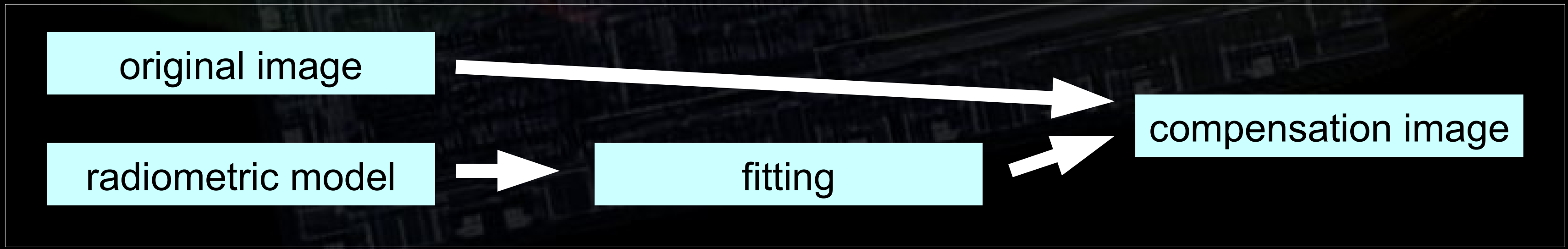
XYZ

Image Fitting

- Consider radiometric model and image content
- Fit image to spatially-varying gamut
- Balance competing properties

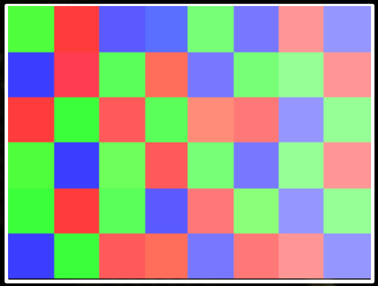
Content Dependence

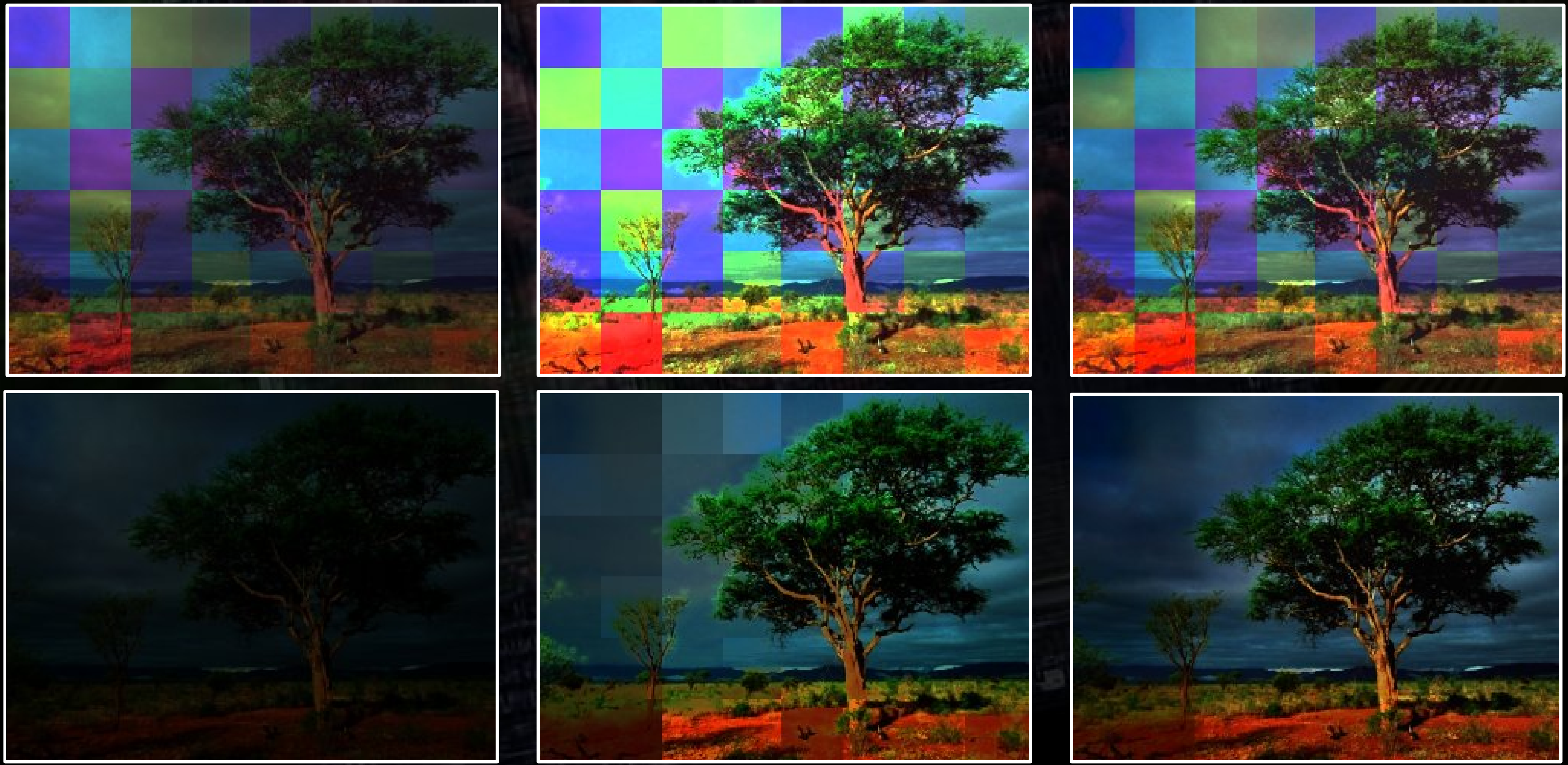
- Fitting is tailored to the radiometric model and the original image



Spatial Variation

- Fit image to spatially-varying gamut





low range, uniform | high range, uniform | spatially varying

Properties

- During image fitting we will balance four properties

Gamut

Extent

Uniformity

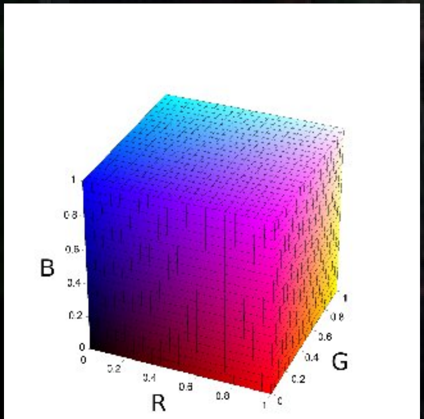
Deviation

Framework

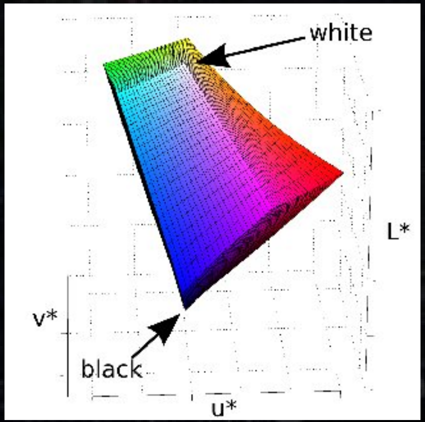
- Desired appearance
- Chrominance fitting
- Range calculation
- Luminance fitting
- Compensation image

Desired Appearance

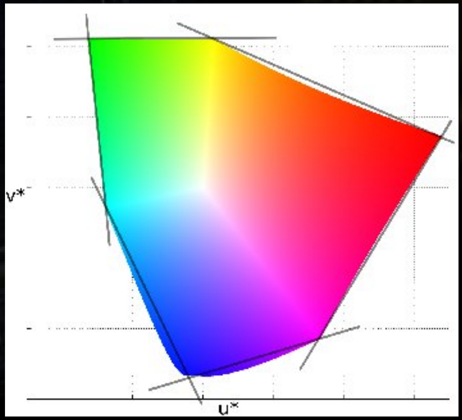
- First we must know the appearance under ideal conditions
  - Original image in sRGB
  - Convert to L*u*v*



sRGB



L*u*v*



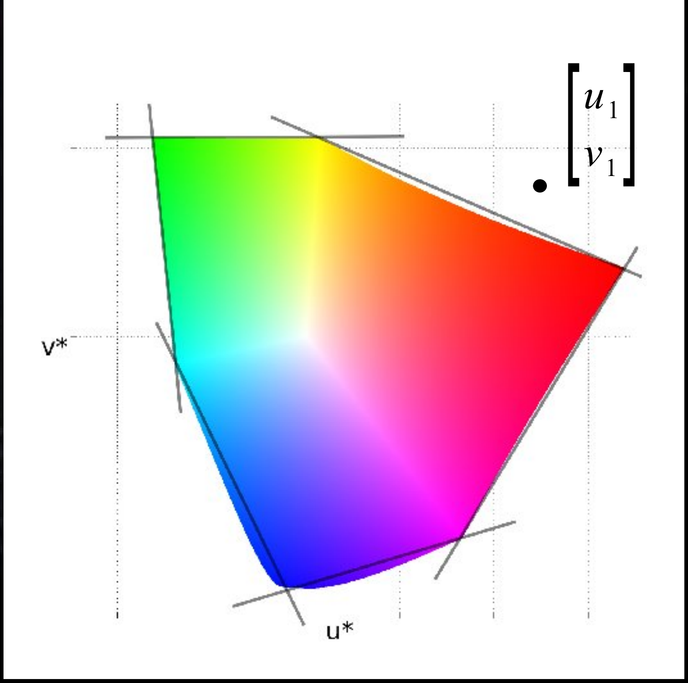
u*v*

Chrominance Fitting

- Compute a transformation to fit the image chrominance to the spatially-varying gamut
  - Find a transformation with three parameters, s, a, b, by minimizing E

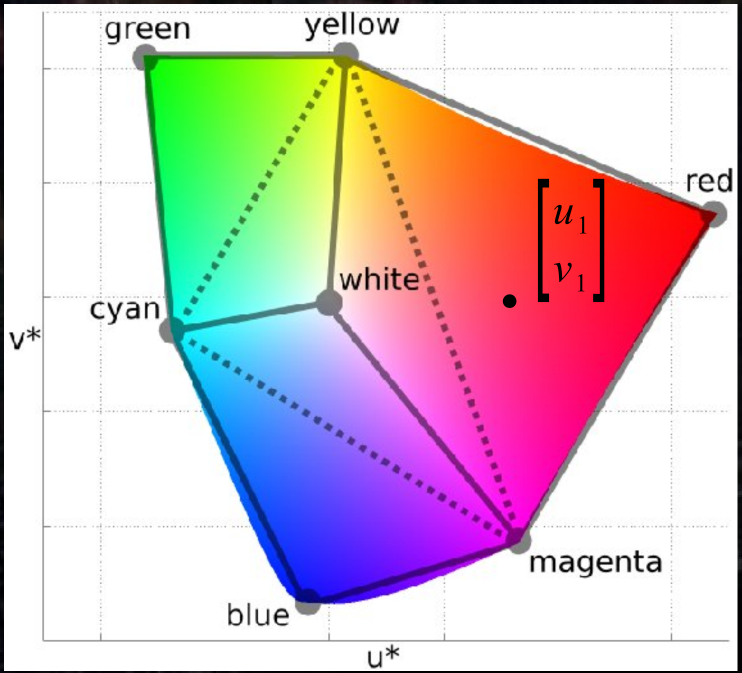
$$\begin{bmatrix} u_1 \\ v_1 \end{bmatrix} = s \begin{bmatrix} u_0 \\ v_0 \end{bmatrix} + \begin{bmatrix} a \\ b \end{bmatrix}$$

$$E = \underbrace{c_1 (1-s)^2}_{\text{extent}} + \underbrace{c_2 (a^2 + b^2)}_{\text{deviation}} + \underbrace{\frac{1}{n} \sum_{\text{pixels}} \sum_{\text{lines}} e^{c_3 (\boldsymbol{r} \cdot \boldsymbol{m} + l_c)}}_{\text{gamut}}$$



Range Calculation

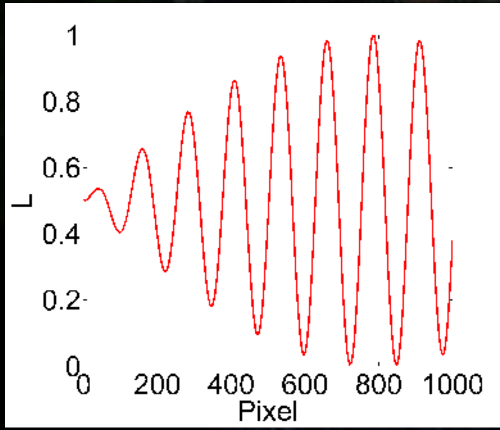
- Calculate a range $[G^l, G^h]$ within which (u_1,v_1) can be produced
  - Approximate the gamut with 12 triangles
  - Linearly interpolate L



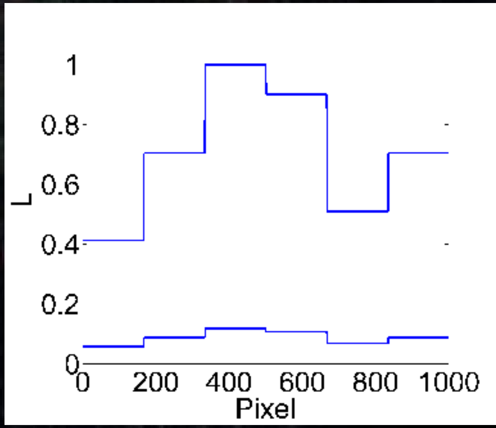
Luminance Fitting

- Fit the image luminance to the previously calculated range
  - Linearly interpolate L_0 between two spatially-varying values

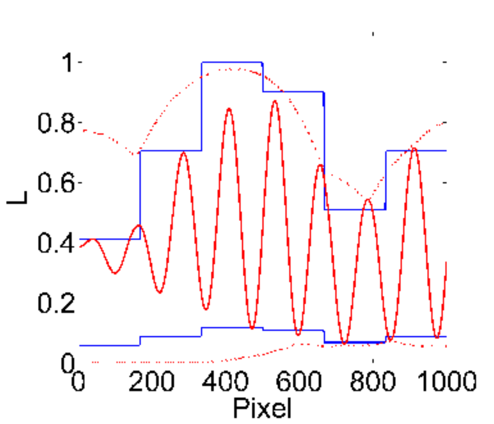
$$L_1 = F^l + (F^h - F^l)\,L_0$$



L_0



G^l and G^h



L_1

Luminance Fitting

- Optimize to get F^l and F^h

$$L_1 = F^l + (F^h - F^l) L_0$$

$$e = \sum_i \sum_j (s_{i,j} + d_1 r_{i,j} + d_2 t_{i,j} + d_3 w_{i,j})$$

$$s = (F_x^l)^2 + (F_y^l)^2 + (F_x^h)^2 + (F_h^h)^2$$

uniformity

$$r = \begin{cases} (L_1 - G^l)^2 & \text{if } L_1 < G_l \\ (L_1 - G^h)^2 & \text{if } L_1 > G_h \\ 0 & \textit{otherwise} \end{cases}$$

gamut

$$t = (F^l)^2 + (F^h - 1)^2$$

$$w = e^{d_4 (F^l - F^h)}$$

extent & deviation

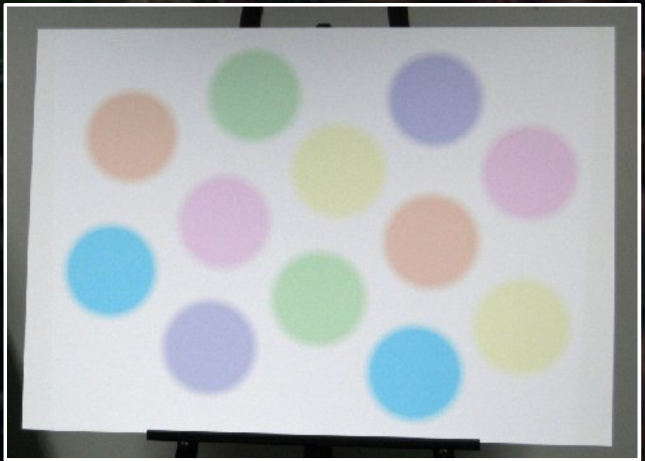
Compensation Image

- Calculate the projector RGB value that will produce the fitted result
  - Convert from L*u*v* to RGB
  - Clip to RGB cube

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet \end{bmatrix} \begin{bmatrix} R \\ G \\ B \\ 1 \end{bmatrix}$$

Results

- Compensating for varying surface colour



surface

compensation image

uncompensated results

compensated result

Results

- Compensating for large variation in surface brightness

surface

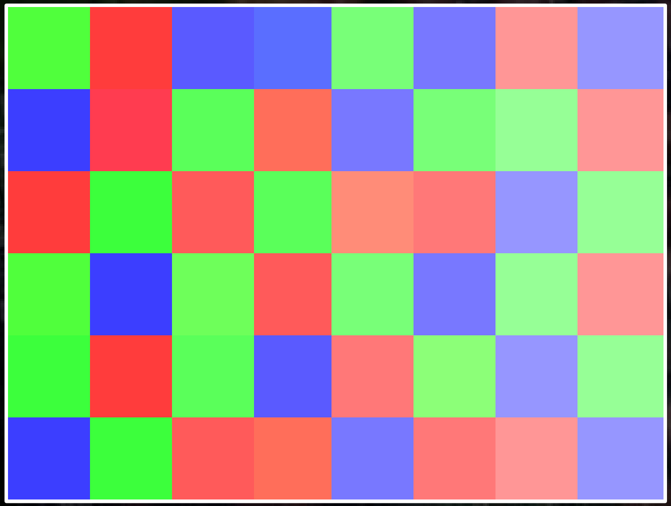
compensation image

uncompensated result

compensated result

Results

- Balancing the various aims


surface


compensation image


uncompensated result


compensated result

Future Work

- Speed
  - Alternative method for optimization
  - Use coarser luminance fitting
- Video
  - Allow image to vary over time
  - Apply temporal uniformity constraint