Characterization for High Dynamic Range Imaging

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Introduction

• Thanks to the high dynamic range (HDR) imaging...
  • Possible to overcome the limit of dynamic range of imaging hardware
  • LDR: saturated, HDR: no saturation

• Meaning of the pixel information in HDR images?
  • So far: no real meaning of values – are just ratios

Propose a simple and accurate technique,
HDR characterization
– Achieve accurate measurement of absolute luminance and color
Background: Color Imaging Workflow

- Scene Radiance
- Energy
  - Camera’s Color Matching Function ≈ Human Eye’s CMF
  - Analogue-to-Digital Converter (ADC)
  - Limited dynamic range

- Energy Amplifying & Quantization of voltage
  - Analogue-to-Digital Converter (ADC)
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- Dig.Vol.
  - Demosaic & De-noising
  - Interpolation of R/G/B channels
  - Non-linear response

- Gamma correction
  - 2.2 $\gamma = 2.2$

- Camera Output
  - (file or display)

Background: Characterization

- Characterization: derive a linear transform between color matching function and camera sensitivity

- Solve linear equation:
  \[ X = (A^T A)^{-1} A^T M \]

- Establish a characterization model from training data, to convert new images into physically meaningful values
Previous Work: Reflectance-based*

**Uses:**
- Spectrophotometer

**Pros:**
- Easy to use
- Cheapest cost

**Cons:**
- Characterize only color (not absolute luminance)
- Only for LDR
- Limited to known illumination (light source spectrum needs to be measured or fixed)

* [PAJ,01;MJ,02;Joh,02;ISO,06; ICC,04;GHS,01]

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Previous Work: Monochromator-based*

**Procedure:**
- Derive actual basis functions for cameras (400-700nm)

**Pros:**
- Rather accurate
- Supports metameristic colors

**Cons:**
- Characterize only color (not absolute luminance)
- Only for LDR
- Expensive devices
- Complicated calibration of the devices

* [MVPC00,MJ02,MVPC03,ISO06,NFG07]
Our Goals: HDR Characterization

- Optimized for HDR imaging
  - Wider color gamut and high dynamic range

- Practical
  - Easy to use
  - Time-efficient

- High accuracy
  - Characterize not only color but absolute luminance
  - Ideally as accurate as spectroradiometer
    (which measures the spectrum of incident light)

Pipeline to Build a Characterization Model

1. Measure physical radiance from the HDR reference target (using a spectroradiometer)
2. Assemble a HDR image from raw CCD responses
3. Build a model from HDR camera responses to radiance measurements in least square sense

\[
\begin{align*}
X &= (A^T A)^{-1} A^T M
\end{align*}
\]
**HDR Reference Target**

- HDR data for learning HDR colors
  - HDR Transparent target: wider gamut & higher dynamic range (4.5:2.0)

- Small gamut; Low dynamic range; Unknown illumination problem

**Measurement Geometry**

- We support unknown illumination conditions:

\[ L(\lambda) = \sum L(\lambda) \tau(\lambda) \triangle \lambda \]

\[ \sum \Phi(\lambda) f_{xy} (\lambda) \triangle \lambda \]

\[ \sum \Phi(\lambda) D_{rgb} (\lambda) \triangle \lambda \]
Using Model with New Test Images

- Transform HDR RGB into CIEXYZ radiance using matrix $X$ at every pixel (physically meaningful)
- For final display: Bradford Chromatic Adaptation from the scene into the display white point (sRGB, D65) with tone-mapping [RSSF, SIG02]

Direct visualization of XYZ

Using Model with New Test Images

- Assembled HDR image from direct CCD response radiance in CIEXYZ [cd/m²] (151.20, 165.58, 153.10)

Before & After

- Before: ordinary HDR images
  - No physical meaning of RGB pixel information
- After: characterized HDR images
  - Contains physical meaning of radiance

Before [RGB: 5.53, 2.21, 0.78] After [RGB: 61.50, 43.50, 2.25]

Difference map (mid-gray = mean, amplified by 10)
Experimental Training/Test

- Trained models from three different cameras:
  
- Test characterization models under different illuminations of high dynamic range:
  
- Training: D55 illuminant
  
- Test: Tungsten (with/wo IR filter), Fluorescent, etc…

Example of Test Set

- Compare the characterization and radiometric measurements
  
- Compute Color Difference (Euclidean Dist.):
  
- CIE \( \Delta E_{00} \), CIE u’v’, CIEXYZ (absolute)
Overall Results of Accuracy

- **Training set:** under 5571K Illumin. [2556 cd/sm²]
  - Test set: under 2946K Illumin. [6508 cd/sm²]
- Significant accuracy even under different illumination

**Color differences ($\Delta E_{00}$): error, performed by Canon 350D**

- **LDR Char.**
- **HDR ICC**
- **Our Method**

Results: Absolute Luminance Accuracy

- **Absolute luminance difference**
  - Between **HDR imaging (camera)** and **spectroradiometer**
- **Canon 350D:**
  - Very similar performance to the spectroradiometer
- **Nikon D100 & D40:**
  - Higher level luminance (due to Nikons’ engineering problem)
Results: Accuracy by Cameras

- Canon 350D:
  - Stable measurement even in different illumination condition
- Nikon models performances:
  - Influenced by infrared lights
  - Faulty IRB filter or Faulty bandwidth

Results: Chromatic Accuracy

- Chromaticity difference:
  - Canon 350D provides high accuracy of chromaticity measurement (except in highly saturated red)
Discussions

- Performance of characterization depends on:
  - Optical quality of digital cameras
  - Engineering limits: Infrared blocking filter, camera bandwidth
  - Lens flare, veiling glare, vignetting: not taken into account
- Potential measurement errors with *metameristic colors*
  - Like other target-based models

Conclusion

- A simple and accurate technique:
  - Characterize HDR imaging systems
  - In terms of absolute luminance and color (radiance at every pixel)
- More accurate
  - Than reflectance-based characterization methods
  - Applicable even in unknown illumination condition
Thank you very much for your attention!

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