A Testing Procedure to Characterize Color and Spatial Quality of Digital Cameras Used to Image Cultural Heritage

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Munsell Color Science Laboratory

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Introduction

- **Past:** Museums, libraries, other cultural-heritage institutions used analog photography to archive their collections.

- **Present & Future:** Choice between continuing to use analog photography or switch to digital photography.
Introduction

• Why stay with analog photography?
  – Lack in funds
  – Lack of knowledge about digital photography
  – “Best practices” have been developed (not yet for digital photography)

• Why switch to digital photography?
  – Easier access to collection by more people around the world
  – Faster photography process
Main purpose

• Provide a testing procedure for characterizing trichromatic (RGB) digital cameras used to digitally archive cultural heritage collections (paintings)
  – Target-based
Ultimate goal of research

• To provide a guideline for high quality digital imaging in a museum setting

• To benchmark camera systems and procedures currently used for digital archiving by the cultural heritage community

-“Direct Digital Image Capture of Cultural Heritage - Benchmarking American Museum Practices and Defining Future Needs” project

- Surveys American museums about their involvement in digital photography
Aims of testing procedure

• Provide only objective measures of quality

• Use software to automate evaluation of test targets and report numbers or graphs describing key image quality parameters
  - Adobe Photoshop
  - MATLAB

• Follow current digital photography standards to the greatest extent possible
Standards

• Consensus standards bodies
  – ISO (International Organization for Standardization)
  – IEC (International Electrotechnical Commission)
  – ANSI (American National Standards Institute)
  – CIE (International Commission on Illumination)
  – NISO (National Information Standards Organization)
Quality parameters being tested

- Tone reproduction / opto-electronic conversion function (OECF)
- System spatial uniformity
- Color reproduction accuracy
- Noise
- Dynamic (tonal) range
- Image flare
- SFR / limiting resolution
- Color channel edge accuracy
- Geometric distortion
- Depth of field / texture reproduction accuracy
Target imaging

- Approximately equal throughout imaging process:
  - Camera - target distance
  - Exposure
  - Lighting set-up
    - Two lights at 45°
- Spectral sensitivity target is only exception
Dark Correction

- Image lens cap 3x
- Find systematic nonzero elements
- Create dark correction image
- Subtract from all other images (except noise images)
Tone reproduction / opto-electronic conversion function (OECF)
System spatial uniformity

- Calculate mean square deviations, percent difference & $\Delta E_{00}$ or $\Delta E^*_{ab}$ from center patch
Spectral Sensitivities

- Monochromator: 10nm intervals from 380nm-780nm
- Measure radiance
- Linearize digital counts w/ OECF
- Divide linearized RGB values by radiance to get relative spectral sensitivities
- Calculate a known metric to determine how colorimetric the digital camera is
  - µ-factor, q-factor, DSC/SMI, UMG
Color reproduction accuracy

- Flat-field using gray card -> \( \frac{R_{\text{chart}}}{R_{\text{gc}}} \times \text{Avg of all } R_{\text{gc}} \)
- 1a. Linearize average DCs of each patch w/ OECF
- 1b. Transform linearized RGB values to XYZ tristimulus value data with an optimized 3x3 matrix
  - CCDC, CCDC + Cobalt blue, Esser + Cobalt blue, IT8
- 2. Transform RGB to XYZ using known color space transform
- Calculate \( \Delta E_{00} \) or \( \Delta E^*_{ab} \) between this data and the measured data (d/0 instrument) for each target
Noise

- ISO standard camera noise

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<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Total SNR</td>
<td>70</td>
</tr>
<tr>
<td>Fixed pattern SNR</td>
<td>115.12</td>
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<tr>
<td>Temporal SNR</td>
<td>88.18</td>
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</tbody>
</table>

- Color Noise
  - Calculate mean and standard deviation of each patch
  - Calculate MCDM
    - Mean of patch
    - $\Delta E_{00}$ or $\Delta E^*_{ab}$ between mean and each pixel of the patch
    - Mean of $\Delta Es$ for patch
Dynamic (tonal) range

- ISO definition:
  - Ratio of the max. luminance level which appears unclipped to the min. luminance level which can be reproduced with an incremental temporal SNR of at least 1.

<table>
<thead>
<tr>
<th>ISO DSC Dynamic Range Ratio</th>
<th>2025.81</th>
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</thead>
<tbody>
<tr>
<td>ISO DSC Dynamic Range (Density)</td>
<td>3.31</td>
</tr>
<tr>
<td>Theoretical Dynamic Range (Density)</td>
<td>3.60</td>
</tr>
</tbody>
</table>
Image flare

- Flat-field using gray card
- Linearize average DCs of each patch w/ OECF
- Determine mean, min. & max. values of 15 gray patches
- Calculate relative root mean standard deviations
SFR / limiting resolution
Color channel edge accuracy

• Determine the spatial coordinates where each channel “sees” edge

<table>
<thead>
<tr>
<th>Edge Location</th>
<th>Slope</th>
<th>Misregistration Shift</th>
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<tbody>
<tr>
<td>21.903</td>
<td>9.476</td>
<td>-0.153 pixels</td>
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<tr>
<td>22.056</td>
<td>9.441</td>
<td>0 pixels</td>
</tr>
<tr>
<td>22.056</td>
<td>9.373</td>
<td>0 pixels</td>
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<table>
<thead>
<tr>
<th>Edge Location</th>
<th>Slope</th>
<th>Misregistration Shift</th>
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</thead>
<tbody>
<tr>
<td>34.588</td>
<td>-0.108</td>
<td>0.191 pixels</td>
</tr>
<tr>
<td>34.397</td>
<td>-0.108</td>
<td>0 pixels</td>
</tr>
<tr>
<td>34.346</td>
<td>-0.108</td>
<td>-0.051 pixels</td>
</tr>
</tbody>
</table>

*Green record used as the reference*
Geometric distortion

• Caused by:
  – Lens
  – Camera not being parallel to object

• Measure size of each dot in image and compare across image

• Measure equivalency of number of pixels across and down the image of the target
Depth of field / texture reproduction accuracy

• Multiply depth of focus distance by cos (57.5°)
Future

- Evaluate and optimize testing procedure in academic research laboratory

- Present testing procedure to panel of experts (camera manufacturers, standards committee members, museum representatives)

- Evaluate testing procedure in American museum environments (case studies)
  - Two methods of evaluation

- Modify Test Procedure
Conclusions

- Determines how well a camera system / workflow is performing

- Cultural heritage institutions can store results as metadata with their images

- Camera manufacturers can see where their cameras need improvements for cultural heritage applications

- Can be used with multi-spectral cameras in the future
Acknowledgements

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Thank you!

http://www.cis.rit.edu/museumSurvey