Development of techniques to Calibrate Digital Cameras and Derive Basic and Advanced Visibility Metrics from Digital Imagery
(or back to the future)

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IMPROVE Steering Committee Meeting
Acadia National Park
7-27-05
Image Preprocessing

- Digital Camera Characterization
- Image Registration
- Clear/Uniform Sky Identification
Digital Camera System (DCS) Image Flow

- Scene-referred Image Data
  - DSC Characterisation Transform (ISO 17321)
  - Proprietary White Balance, Flare Removal, Demosaicing
  - ICC Colorimetric Profiles go with these
- Original-referred Image Data
  - Proprietary Colour Rendering (viewing conditions, gamut mapping)
- Standard Output-referred Image Data
  - Proprietary Colour Rendering (preferred - white level, tone curves, gamut mapping, dodging & burning)
  - Output Device Color Map or ICC Perceptual Profile
- Output Device Image Data (not colorimetric)

Raw DSC Image Data (not colorimetric)
DCS Characterization

• MacBeth Digital ColorChecker SG
• Photo Research 650 Spectroradiometer
• D65 Daylight light source
• Olympus C-730 Digital Camera
• LOTS of TIME
Measurement Repeatability
Opto-electronic Conversion Function

Digital Camera Measured OECF

Digital ColorChecker® SG

Camera DN

Lineraized DN

R

G

B
Two sets of measurement triplets from MacBeth CC patches (n=24)
Linearized RGB from digital camera and XYZ from spectroradiometer

\[ P = AV \]

\[ A_X = (V^TV)^{-1} (V^TP_X) \]
Polynomial Solutions

- $X = a_1R + a_2G + a_3B$  \hspace{1cm} (3 x 3)

- $X = a_1R + a_2G + a_3R + a_4RG + a_5RB + a_6GB$  \hspace{1cm} (3 x 6)

- $X = a_1R + a_2G + a_3R + a_4RG + a_5RB + a_6GB + a_7R^2 + a_8G^2 + a_9B^2$  \hspace{1cm} (3 x 9)

- $X = a_1R + a_2G + a_3R + a_4RG + a_5RB + a_6GB + a_7R^2 + a_8G^2 + a_9B^2 + a_{10}1$  \hspace{1cm} (3 x 10)

- $X = a_1R + a_2G + a_3R + a_4RG + a_5RB + a_6GB + a_7R^2 + a_8G^2 + a_9B^2 + a_{10}1 + a_{11}RGB$  \hspace{1cm} (3 x 11)
DCS Characterization

- Measure all 96 patches
- Linearize RGB data with 14 step grayscale
- Calculate coefficients using 24 CC patches for possible polynomials
- Calculate predicted XYZ for all 96 patches
- Convert measured and predicted XYZ to Lab
- Calculate deltaE94 between measured Lab and predicted Lab
- Determine which polynomial has least error

A = \((N^TN)^{-1}(N^TP)\)

\((XYZ) = A(RGB)\)

\((Lab) = B(XYZ)\)

\[\text{deltaE94} = (\Delta L^2/k_1 + \Delta a^2/k_2 + \Delta b^2/k_3)^{1/2}\]
## deltaE94: Measured vs. Predicted

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<thead>
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<th>Coeff.</th>
<th>Avg</th>
<th>Max</th>
<th>Min</th>
<th>White</th>
<th>Mid-Gray</th>
<th>Black</th>
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<td>5.2</td>
<td>23.7</td>
<td>0.7</td>
<td>3.3</td>
<td>17.1</td>
<td>2.2</td>
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<td>3 x 6</td>
<td>4.4</td>
<td>23.0</td>
<td>0.6</td>
<td>0.6</td>
<td>16.8</td>
<td>2.9</td>
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<td>3 x 9</td>
<td>6.4</td>
<td>25.2</td>
<td>0.6</td>
<td>16.7</td>
<td>19.4</td>
<td>2.7</td>
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<tr>
<td>3 x 10</td>
<td>3.7</td>
<td>13.0</td>
<td>0.2</td>
<td>0.2</td>
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<td>3 x 11</td>
<td>3.8</td>
<td>11.5</td>
<td>0.1</td>
<td>0.1</td>
<td>12.1</td>
<td>1.5</td>
</tr>
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</table>
Image Preprocessing

• Digital Camera Characterization

• Image Registration

• Clear/Uniform Sky Identification
Registration

• Each image is registered to account for camera movement or misalignment. Registered images are necessary for target/sky contrast, as well as other image metrics.

• Compares B/W version of candidate image to reference B/W image pixel by pixel. B/W binary comparison is used to eliminate shading and color influences.

• Candidate image “walks” one pixel at a time in a spiral pattern until the 50 by 50 pixel test areas in the candidate and reference images have a 98% match.

• Results of registration are horizontal and vertical offsets. They are save in the image database for use by the image metric algorithms. The original images are not affected.

• The registration target must be close enough to be visible for all air quality conditions, but be far enough away to minimize parallax float problems (small registration error causing large errors in scene element locations).
Clear Sky Identification

- Each image is tested for cloud free (clear sky) conditions. Clear sky conditions are necessary for target/sky contrast, as well as other image metrics.

- Five vertical regions are scanned for discontinuities in the red band of the RGB color triplet.

- This technique correctly identifies cloud free images 95% of the time.

- Not possible to determine if images or scenes are completely cloud free because entire sky is not visible.
Calculation of Visual Air Quality Metrics

- apparent target \((C_r)\) contrast
- \(b_{ext}\) from apparent target contrast
- image difference metrics:
  - pixel-by-pixel \(\Delta E\)
  - image average \(\Delta E\)
- image difference metrics based on Human Visual System (HVS) models: S-CIELAB, dcTune, iCAM, others
Semi-Automatic Quarterly Reports

Great Smoky Mtns National Park
Image Analysis - First Quarter 2005

![Graphs and data tables related to image analysis for the first quarter of 2005.]

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Image Analysis - First Quarter 2005

![Graphs and data tables related to image analysis for the first quarter of 2005.]

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Image Collection Statistics for Morning (9:00 - 10:45 AM) and Afternoon (1:00 - 2:45 PM)

<table>
<thead>
<tr>
<th></th>
<th>Morning</th>
<th>Afternoon</th>
</tr>
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<tbody>
<tr>
<td>Number of Images Possible (15 minute intervals)</td>
<td>1440</td>
<td></td>
</tr>
<tr>
<td>Number of Images Captured</td>
<td>1098</td>
<td></td>
</tr>
<tr>
<td>Number of Images Captured with Minimal Cloud Cover</td>
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<tr>
<td>Percent of Images Captured with Minimal Cloud Cover</td>
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</tbody>
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Image Collection Statistics for Afternoon (9:00 - 10:45 AM) and Morning (1:00 - 2:45 PM)

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<td>Percent of Images Captured with Minimal Cloud Cover</td>
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Grand Canyon National Park

$b_{\text{ext}}$ from Digital Images vs. $b_{\text{sp}}$ from Nephelometer


All Images & Non-WX $b_{\text{sp}}$

Clear Skies & Non-WX $b_{\text{sp}}$
Calculation of Visual Air Quality Metrics

• apparent target ($C_r$) contrast
• $b_{ext}$ from apparent target contrast
• image difference metrics:
  pixel-by-pixel deltaE
  image average deltaE
• image difference metrics based on Human Visual System (HVS) models: S-CIELAB, dcTune, iCAM, Sarnoff, and MANY others
Image Modulation Depth

\[
I_{m(\text{rgb})} = \frac{1}{(n-1)E_{(\text{rgb})}} \left[ \sum_{i=1}^{n} (E_{i(\text{rgb})} - \overline{E_{(\text{rgb})}})^2 \right]^{1/2}
\]

\[
\text{ModDepth} = \left( I_{m(r)}^2 + I_{m(g)}^2 + I_{m(b)}^2 \right)^{1/2}
\]
GRCA 1500 hrs Image Analysis

deltaE94 & dcTune JND

Pixel-by-pixel deltaE94

Image average deltaE94

dcTune 2.0 JND

Image average deltaE94
GRCA 1500 hrs Image Analysis

$b_{\text{ext}}$ from target contrast vs. Image Average deltaE94
GRCA WinHaze Images

![Graphs showing the relationship between image modulation depth and b_{ext} (Mm^{-1}) and deltaE_{94}](image)
Current Status

• Digital images can be automatically registered, and categorized for further analyses
• Digital cameras can be reasonably characterized allowing the calculation of various image metrics
• Tests indicate that for “clear sky” images these various metrics can be related to onsite optical measurements
Current Status

• Operational at Grand Canyon NP, Great Smoky Mountains NP, and Phoenix, AZ providing Automatic Monthly and Semi-automatic Quarterly summaries of $b_{ext}$ and Visual Range

• Is available for other locations depending on funding by clients
On going (ARS Funded) Work

• Automate characterization hardware
• Examine and include flare and image plane uniformity corrections
• Test various digital cameras by characterizing the systems, take simultaneous images of scenic vistas, calculate and compare visual air quality metrics calculated from different cameras for same scene
• Development of additional data products