MEASUREMENT-BASED COLOR CORRECTION METHOD FOR 3D SCANNING SYSTEM

SPEAKER: KAI-LIN CHAN

ADVISOR: TZUNG-HAN LIN, HUNG-SHING CHEN

Graduate Institute of Color and Illumination Technology, NTUST CIT
Why do we need 3D scanning?

How does 3D scanner work?

Color Corrections & Evaluations

• 2D Color Correction

• 3D Color Correction
WHY
Personal Statue

Virtual Reality

3D Scanning

Augmented Reality

Something Memorable

Specific Application

Fetus
HOW

Watch CI3D Scanner Video
3D Scanning Steps

- **Light Source**
- **Laser**
- **Stereo Camera**
- **Turntable**
- **Scanned Object**
3D Scanning Result

- Color Texture Images
COLOR CORRECTION
Experiment Route

1. Scanned 3D Model
2. One Lens of Stereo Camera
3. Color Texture Images (Raw)
4. X-rite ColorChecker
5. 2D Color Correction
6. 2D Colorimeter (Topcon UA-1000A)
7. Calibration Ball
8. 2D Color Correction
9. 3D Color Correction
10. 2D Colorimeter (Topcon UA-1000A)
11. Evaluation
12. Corrected 3D Model
2D Color Correction

3D Color Correction
2D COLOR CORRECTION
Uniformity Correction  →  Camera Color Correction
Uniformity Correction
# Uniformity Correction

<table>
<thead>
<tr>
<th></th>
<th>Raw</th>
<th>Uniformity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>White Board</strong></td>
<td>![Raw Image]</td>
<td>![Uniformity Image]</td>
</tr>
<tr>
<td><strong>ColorChecker</strong></td>
<td>![Raw Image]</td>
<td>![Uniformity Image]</td>
</tr>
</tbody>
</table>
Reference Values of ColorChecker
Polynomial Regression

Uniformity Correction

Topcon UA-1000A (Ref.)

\[
\begin{bmatrix} A \end{bmatrix}_{24 \times N} \times \begin{bmatrix} M \end{bmatrix}_{N \times 3} = \begin{bmatrix} B \end{bmatrix}_{24 \times 3}
\]

- \([A]\) and \([B]\) are normalized RGB, which is normalized to 0~1.
Camera Color Correction

Uniformity

Polynomial Regression

The 1\textsuperscript{st} Order

The 2\textsuperscript{nd} Order

- The 1\textsuperscript{st} Order: $[A] = [R, G, B, K]$, $K$ is constant
- The 2\textsuperscript{nd} Order: $[A] = [R^2, G^2, B^2, RG, GB, RB, R, G, B, K]$, $K$ is constant
2D Color Correction – Color Difference Comparison

<table>
<thead>
<tr>
<th>Colorchecker</th>
<th>Raw</th>
<th>Uniformity Correction</th>
<th>The 1\textsuperscript{st} Order</th>
<th>The 2\textsuperscript{nd} Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration Ball</td>
<td><img src="image1.png" alt="Raw" /></td>
<td><img src="image2.png" alt="Uniformity Correction" /></td>
<td><img src="image3.png" alt="The 1\textsuperscript{st} Order" /></td>
<td><img src="image4.png" alt="The 2\textsuperscript{nd} Order" /></td>
</tr>
<tr>
<td>$\Delta E^*_{94}$</td>
<td>25</td>
<td>9</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

- $\Delta E^*_{94}$ is calculated according to ColorChecker.
3D COLOR CORRECTION
What is Final Target?

2D Color Correction

Topcon UA-1000A (Ref.)

- Polynomial Regression
- Look-up Table
Polynomial Regression

2D Color Correction

Topcon UA-1000A (Ref.)

\[
\begin{bmatrix} A \end{bmatrix}_{37 \times N} \times \begin{bmatrix} M \end{bmatrix}_{N \times 1} = \begin{bmatrix} B \end{bmatrix}_{37 \times 1}
\]

• [A] and [B] are stimulus values, Y.
Polynomial Regression

2D Color Correction

Polynomial Regression

The 1<sup>st</sup> Order

The 2<sup>nd</sup> Order

- The 1<sup>st</sup> Order: \([A] = [Y]\)
- The 2<sup>nd</sup> Order: \([A] = [Y^2, Y] \)
Look-up Table

Ratio Table
### 3D Color Correction – Color Difference Comparison

<table>
<thead>
<tr>
<th></th>
<th>Raw</th>
<th>2DC</th>
<th>3D_1\textsuperscript{st} (Luminance)</th>
<th>3D_2\textsuperscript{nd} (Luminance)</th>
<th>LUT (Color)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Calibration Ball</strong></td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
<td><img src="image5" alt="Image" /></td>
</tr>
<tr>
<td><strong>Scanned Model</strong></td>
<td><img src="image6" alt="Image" /></td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
<td><img src="image9" alt="Image" /></td>
<td><img src="image10" alt="Image" /></td>
</tr>
<tr>
<td>(\Delta E^*_{94})</td>
<td>24.7</td>
<td>15.7</td>
<td>15.5</td>
<td>15.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- \(\Delta E^*_{94}\) is calculated according to calibration ball.
- 2DC: 2D Color Correction
- 3D_1\textsuperscript{st}: 3D Color Correction–1\textsuperscript{st} Order Polynomial Regression
- 3D_2\textsuperscript{nd}: 3D Color Correction–2\textsuperscript{nd} Order Polynomial Regression
- LUT: 3D Color Correction–Look-up Table
3D Color Correction – Luminance Distribution Curve

pixel 1

pixel n

Position (pixel)

Luminance (Y)

Raw
Raw+2DC
Raw+2DC+3D-1st
Raw+2DC+3D-2nd
Raw+2DC+LUT
### 3D Color Correction – Contrast Ratio

<table>
<thead>
<tr>
<th>Calibrating Ball</th>
<th>Raw</th>
<th>2DC</th>
<th>3D\textsubscript{1}\textsuperscript{st} (Luminance)</th>
<th>3D\textsubscript{2}\textsuperscript{nd} (Luminance)</th>
<th>LUT (Color)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Ball</td>
<td><img src="image" alt="Raw" /></td>
<td><img src="image" alt="2DC" /></td>
<td><img src="image" alt="3D\textsubscript{1}\textsuperscript{st}" /></td>
<td><img src="image" alt="3D\textsubscript{2}\textsuperscript{nd}" /></td>
<td><img src="image" alt="LUT" /></td>
</tr>
<tr>
<td>Contrast Ratio</td>
<td>16:1</td>
<td>3:1</td>
<td>3:1</td>
<td>2:1</td>
<td>2:1</td>
</tr>
</tbody>
</table>

- Calibrating Ball images represent calibration standards.
- Contrast Ratio values show the range of contrast ratios for each correction method.
Overall of Results

Scanned 3D Model → 2D Color Correction (The 2\textsuperscript{nd} Order) → 3D Color Correction (Look-up Table)
CONCLUSION
Proposed Color Correction for 3D Scanning

- 2D Color Correction
  - The 1\textsuperscript{st} Order Polynomial Regression
  - The 2\textsuperscript{nd} Order Polynomial Regression
- 3D Color Correction
  - The 1\textsuperscript{st} Order 3D Color Correction
  - The 2\textsuperscript{nd} Order 3D Color Correction
- Look-up Table
2D Color Correction

- Correction tool is **ColorChecker**
- Polynomial regression based on **normalized** RGB is better
- The 2\text{nd} order polynomial regression is better than the 1\text{st} order

3D Color Correction

- Correction tool is **calibration ball**
- **Look-up table method** has the best performance of all

- All the correction can be applied on realistic 3D scanned object well.
FUTURE WORK
Different material of calibration ball for 3D Color Correction

High-end DSLR replaces 2D colorimeter to capture reference values
THANK YOU.