Investigation of the Implementation Aspects of the MI Condition

David R. Wyble
Avian Rochester, LLC

John Seymour
Quadtech Inc.
A Tale of Two Instruments

Non-fluorescent samples: Instrument #1 CIELAB = Instrument #2 CIELAB

Fluorescent samples: Instrument #1 CIELAB ≠ Instrument #2 CIELAB
A Tale of Two Instruments

Non-fluorescent samples: Instrument #1 CIELAB = Instrument #2 CIELAB

Fluorescent samples: Instrument #1 CIELAB ≠ Instrument #2 CIELAB

The discrepancy is caused by the difference in instrument source content in the **excitation region** of the fluorescent sample.
Questions For Today

Given the powerful combination of FTS standards and bispectral data:

1. Are ISO 3664 and ISO 13655 adequate for the evaluation of instrument sources?

2. Using various hypothetical instrument sources how do measurements of the acrylic standards compare?
Questions For Today

Given the powerful combination of FTS standards and bispectral data:

1. Are ISO 3664 and ISO 13655 adequate for the evaluation of instrument sources?

2. Using various hypothetical instrument sources how do measurements of the acrylic standards compare?
FTS Acrylic Standards

- FTS standards sourced from Avian Technologies, LLC. Previously made by Color Control Systems. Same products, same formulations.

- FTS = Fluorescent Transfer Standards. Also to pay homage to the late Frederick T Simon, who originally developed the product line.

- Inorganic fluorescent compounds intended to mimic the behavior of typical paper OBAs.

- Full disclosure…
FTS Acrylic Standards

<table>
<thead>
<tr>
<th></th>
<th>17b</th>
<th>15a</th>
<th>13a</th>
<th>11a</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIE W</td>
<td>155</td>
<td>142</td>
<td>128</td>
<td>108</td>
</tr>
</tbody>
</table>
NRC Measurements

CIE Illuminants

“Total Radiance Factor”

FTS
Bispectral Measurements

• Think reflectance but in 2D.
• Each column represents a complete reflected spectrum at one incident wavelength.
Bispectral Measurements

- Think reflectance but in 2D.
- Each column represents a complete reflected spectrum at one incident wavelength.
Bispectral Measurements

- Think reflectance but in 2D.
- Each column represents a complete reflected spectrum at one incident wavelength.
Bispectral Calculations

sum over all detection wavelengths (excluding diagonal) to find the “excitation region”

sum over all incident wavelengths (excluding diagonal) to find the “emission region”
On to the questions:

Are ISO 3664 and ISO 13655 adequate for the evaluation of instrument sources?

<table>
<thead>
<tr>
<th>Chromaticity</th>
<th>Difference from D50 ($u',v'$)</th>
<th>$U'_{10}$</th>
<th>$V'_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>D50</td>
<td>0.2101</td>
<td>0.4889</td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>0.2099</td>
<td>0.4885</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>0.000491533</td>
<td></td>
<td>Passed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Colour Rending Index</th>
<th>Average $R_i = Ra$</th>
<th>Minimum $R_i$</th>
<th>Passed</th>
<th>Passed</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Visible Metamerism Index</th>
<th>Average $\Delta E^*$</th>
<th>Rating: (A, B, C, D, E)</th>
<th>Passed</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>UV Metamerism Index</th>
<th>Average $\Delta E^*$</th>
<th>Rating: (A, B, C, D, E)</th>
<th>Passed</th>
</tr>
</thead>
</table>

Source is a conforming D50 simulator

Danny Rich
On to the questions:

Are ISO 3664 and ISO 13655 adequate for the evaluation of instrument sources?

Danny Rich
On to the questions:

Are ISO 3664 and ISO 13655 adequate for the evaluation of instrument sources?

- Chromaticity
- Color Rendering Index
- Visible Metamerism Index
- UV Metamerism Index

Danny Rich
Three Ways to Achieve M1

Simply match the D50 spectral power distribution

Adjust the UV to achieve D50 colorimetry (single flash, Gärtner and Griesser)

Mix reflectance from high and low UV sources to achieve D50 colorimetry. (dual flash, Imura)
Three Ways to Achieve M1

Simply match the D50 spectral power distribution

Adjust the UV to achieve D50 colorimetry (single flash, Gärtner and Griesser)

Mix reflectance from high and low UV sources to achieve D50 colorimetry. (dual flash, Imura)
Experiment

Hypothetical Illuminants

“Total Radiance Factor”

FTS tiles

CIELAB
Virtual Sources 1: CIE Daylight

CIE Daylight between 4976K and 5028K are M1 complaint. The range is only about 1/2%
Virtual Sources 1: CIE Daylight

<table>
<thead>
<tr>
<th>FTS</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>11a</td>
<td>0.003</td>
<td>0.047</td>
</tr>
<tr>
<td>13a</td>
<td>0.007</td>
<td>0.078</td>
</tr>
<tr>
<td>15a</td>
<td>0.008</td>
<td>0.118</td>
</tr>
<tr>
<td>17b</td>
<td>0.010</td>
<td>0.133</td>
</tr>
</tbody>
</table>

Ranges
Virtual Sources 1: CIE Daylight

But can we measure it?

Yes.
## Virtual Sources 1: CIE Daylight

<table>
<thead>
<tr>
<th>FTS</th>
<th>$a^*$</th>
<th>$b^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>11a</td>
<td>0.003</td>
<td>0.047</td>
</tr>
<tr>
<td>13a</td>
<td>0.007</td>
<td>0.078</td>
</tr>
<tr>
<td>15a</td>
<td>0.008</td>
<td>0.118</td>
</tr>
<tr>
<td>17b</td>
<td>0.010</td>
<td>0.133</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FTS</th>
<th>$a^*$</th>
<th>$b^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>11a</td>
<td>0.001</td>
<td>0.013</td>
</tr>
<tr>
<td>13a</td>
<td>0.000</td>
<td>0.024</td>
</tr>
<tr>
<td>15a</td>
<td>0.001</td>
<td>0.041</td>
</tr>
<tr>
<td>17b</td>
<td>0.003</td>
<td>0.044</td>
</tr>
</tbody>
</table>

Compliant CIE Daylight

$$\lambda \leq 400 = 0$$
Virtual Sources 1: CIE Daylight

<table>
<thead>
<tr>
<th>FTS</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>11a</td>
<td>0.001</td>
<td>0.013</td>
</tr>
<tr>
<td>13a</td>
<td>0.000</td>
<td>0.024</td>
</tr>
<tr>
<td>15a</td>
<td>0.001</td>
<td>0.041</td>
</tr>
<tr>
<td>17b</td>
<td>0.003</td>
<td>0.044</td>
</tr>
</tbody>
</table>

Compliant CIE Daylight
\[ \lambda \leq 400 = 0 \]

Typical UV Cut Filter

Fully eliminate Fluorescent Emission
Virtual Sources 2: Scale D50 UV

![Graph showing relative power vs. wavelength (nm)]
Virtual Sources 2: Scale D50 UV

±40%: still M1 complaint
### Virtual Sources 2: Scale D50 UV

#### FTS | a* | b*
---|---|---
11a | 0.69 | 2.82
13a | 1.13 | 4.41
15a | 1.51 | 6.15
17b | 1.98 | 7.28

**Ranges**
## Virtual Sources 2: Scale D50 UV

<table>
<thead>
<tr>
<th>FTS</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>11a</td>
<td>0.69</td>
<td>2.82</td>
</tr>
<tr>
<td>13a</td>
<td>1.13</td>
<td>4.41</td>
</tr>
<tr>
<td>15a</td>
<td>1.51</td>
<td>6.15</td>
</tr>
<tr>
<td>17b</td>
<td>1.98</td>
<td>7.28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FTS</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>11a</td>
<td>0.12</td>
<td>0.51</td>
</tr>
<tr>
<td>13a</td>
<td>0.18</td>
<td>0.76</td>
</tr>
<tr>
<td>15a</td>
<td>0.23</td>
<td>0.99</td>
</tr>
<tr>
<td>17b</td>
<td>0.29</td>
<td>1.16</td>
</tr>
</tbody>
</table>

### Compliant Scaled UV

\[ \lambda \leq 400 = 0 \]
Conclusions for question #1

Are ISO 3664 and ISO 13655 adequate for the evaluation of instrument sources?

<table>
<thead>
<tr>
<th>Metric</th>
<th>CIE Daylight</th>
<th>Scaled UV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromaticity</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>CRI</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Visible Metamerism</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>UV Metamerism</td>
<td>✓</td>
<td>X</td>
</tr>
</tbody>
</table>

Which metrics bound compliance for these sources?
Conclusions for question #1

Are ISO 3664 and ISO 13655 adequate for the evaluation of instrument sources?

Large b* range!

\[ a^* -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 \\
-15 -14 -13 -12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 \]
Question #2

Using various hypothetical instrument sources how do measurements of the acrylic standards compare?

To reasonably model instrument sources, we first examine four currently implemented instrument sources:

• Barbieri SpectroPad Series 2
• Techkon SpectroDens
• Konica-Minolta FD-7
• X-Rite eXact, and i1Pro
Real World M1

Barbieri SpectroPad Series 2

“Thanks to 7 LEDs, D50 illumination is reached. This illumination is based on LED technology by Just Normlicht. It fully matches the new measurement condition M1 introduced with the ISO standard 13655-2009.”
Real World M1

Techkon SpectroDens

“Using the latest LED technology, the new SpectroDens provides D50 illumination and therefore fulfills the M0 – M3 measuring conditions in accordance to ISO 13655.”
Real World M1

Konica-Minolta FD-7

Product literature mentions their “Virtual Fluorescent Standard”, which is a phrase used in the dual-flash papers by Imura. We infer that the FD-7 uses the two flash method. Their literature also states that the light source is LED based.
Real World M1

X-Rite eXact, and i1Pro

Product literature refers to “gas filled tungsten (illuminant type A) and UV LED”. It is not clear the precise method of the i1Pro. An X-Rite patent describes a method similar to the two-flash.

Note that the X-Rite Isis is based on an i1Pro. Also, the i1Pro is the OEM for the EFI ES-2000.
Real World M1

Existing Instrument Summary

This short review demonstrates that different companies have implemented the M1 condition by the use of different physical light sources. Thus, there is at least the potential for this to be a source of disagreement between different models of spectrophotometer.

Forgive the legalese: The authors are not endorsing any of these products, nor are they necessarily agreeing with the claims of the product literature we reference. Our sole criterion was the claim of M1 compliance.
Real World Results

Facility #1: A, B1, C1, D
Facility #2: B2, C2, E (no 9a)

M1 condition
D50/2°
CIELAB

Inst A
Inst B1, B2
Inst C1, C2
Inst D
Inst E
NRC D50

9a
11a
13a
15a
17b

Real World Results

M1 condition
D50/2°
CIELAB

Facility #1: A, B1, C1, D
Facility #2: B2, C2, E (no 9a)
Hypothetical Sources

Four sources were modeled, each with an adjustable UV component and one or more visible components.
Experimental Procedure

We illuminate a fluorescent sample with D50 and the test source. Adjust UV component to minimize $\Delta E^*_{ab}$
Experiment: Two Paths to CIELAB

Hypothetical Instrument

“Total Radiance Factor”

FTS tiles or paper

CIELAB
Experiment: Two Paths to CIELAB

D50

“Total Radiance Factor”

FTS tiles or paper

CIELAB
Experimental Results: $\Delta E_{ab}$ to D50

Is the FTS tile as good a standard as paper?
Experimental Results: $\Delta E_{ab}$ to D50

Is the FTS tile as good a standard as paper?
Experimental Results: $\Delta E_{ab}$ to D50

Is the FTS tile as good a standard as paper?
Experimental Results: $\Delta E_{ab}$ to D50

Is the FTS tile as good a standard as paper?
Experimental Results: $\Delta E_{ab}$ to D50

Is the FTS tile as good a standard as paper?
Experimental Results: $\Delta E_{ab}$ to D50

Is the FTS tile as good a standard as paper?
Experimental Results: $\Delta E_{ab}$ to D50

Is the FTS tile as good a standard as paper?
Experimental Results: $\Delta E_{\text{ab}}$ to D50

Is the FTS tile as good a standard as paper?
Conclusions for question #2

Using various hypothetical instrument sources how do measurements of the acrylic standards compare?

• Calibrating against paper does produce slightly better results.

• We believe that the difference between the test sources and D50 accounts for more of the color differences.

• The technique can expose the differences between illumination technologies.
Future Work

• Modeling of the dual flash method.

• Better understanding of the implications of differences in the bispectral matrices of paper and FTS standards.

• Can the acrylic standards adequately simulate the behavior of the fluorescent compounds in commercial papers?

• How might acrylic fluorescent standards be applied to the instrument profiling process?
Acknowledgements

• Danny Rich of SunChemical Corp, for generously sharing his spreadsheet used for evaluating illuminants.

• Gerry Gerlach of Integrity Graphics and IdeAlliance, for asking important questions, and for loaning his (borrowed) KonicaMinolta FD-7 spectrophotometer.

• Techkon USA for loaning their SpectroDens spectrophotometer.

• Tom Lianza of PhotoResearch Inc, for the use of his X-Rite exact spectrophotometer.

• Max Derhak of Onyx Graphics, for facilitating the Barbieri measurements on the Onyx Spectro Pad 2 spectrophotometer.

• A list of people, many of whom I don’t even know, that have been exchanging email for a few months on many related topics: Danny Rich, Gerry Gerlach, Mike Rodriguez, Roy Bohnen, Ronald Tomey, Steve Smiley, David McDowell, David Steinhardt, Gary Russell, Claas Bickeböller, Mark Lombardi, Ray Cheydleur, Jodi Baker.

• Avian Technologies, LLC, for travel funding.
Thank you