Inter-Instrument Agreement for M1 Conditions and Its Implications for Graphic Reproduction

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ISO 13655 Spectral measurement & colorimetric computation

- The ISO Standard has created a series of measurement conditions known as the M-series
  - M1 is a close simulation of CIE D50 as defined by ISO 3664
  - M0 is the traditional incandescent lamp used in older instruments
  - M2 is any lamp with the UV removed
  - M3 is any lamp with a polarizer and analyzer in the optics
- No known sources have the right spectral distribution and size for conformance to both ISO 13655 M1 and instrument geometry.
  - So the standard requires an undeveloped technology to achieve full conformance to an M1 option a instrument source

ISO 13655 Spectral measurement & colorimetric computation

- Reproduction engineers are particularly concerned with production substrates that contain OBA
- Many proofing substrates contain no FWA and so there is difference in the appearance of the substrates

ISO 13655 Spectral measurement & colorimetric computation

- The ISO Standard has always recommended the use of CIE D50 for colorimetric computations
- In 2009 it adopted the requirements of ISO 3664:2009 and now requires a CIE D50 simulator
  - The preference is to have a close simulation of D50 being used to acquire the spectral data.
- CIE D50 simulators require lamps with both visible and ultraviolet radiations in the correct ratios.
  - Paper, Textiles and Plastics industry use large integration sphere (150mm diameter) and xenon lamps to create the desired mix of UV and VIS radiations.
  - The changes in ISO 3664 and ISO 13655 were implemented to handle the presence of OBA in the paper substrate

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- CIE Publication 176 reported on the magnitude of the errors encountered
  - Differences in apparent reflectance was directly attributable to the presence of OBA in the paper.
  - Differences of up to 3 CIELAB units were reports for solids
  - Differences of up to 12 CIELAB units were reports for tones.

ISO 13655 Spectral measurement & colorimetric computation

- It was determined important that the total radiance factor of the substrate be captured correctly — with the UV content of D50
  - The paper industry accomplishes this by using large integrating sphere with UV-rich xenon lamps and UV blocking filters
  - The use of a UV blocking filter was first reported by Gaertner and Griesser.
  - The ratio of the UV to the VIS is controlled by removing some UV until the correct ratio is obtained.
  - The Griesser method requires space between the lamp and the influx optics
  - This space in not available in a portable, hand-held 45:0 instrument, as required by ISO 13655
  - Some other method of obtaining the M1 condition is required.

ISO 13655 Spectral measurement & colorimetric computation

- ISO 13655 provides for an alternative method to providing an exact simulation of CIE Illuminant D50
  - There are many published approaches to obtaining the total spectral radiance factor
    - Most approaches require constructing one or more sources with varying amounts of UV Radiations
  - Imura proposed the "virtual fluorescent standard" or VFS method in a series of articles in the journal Color Research and Application
  - This approach has proved to be the most widely applied commercial method for adjusting relative total spectral radiance factor readings to the values that would have been acquired had the instrument used an exact D50 simulator as the source
  - All instruments in this study incorporated the Imura VFS method
Experimental Procedure

- 50 Papers stocks were selected including:
  - publication stocks
  - label stocks
  - office papers
  - packaging papers
  - boards
- CIE Whiteness Index (per ASTM E313) ranged from 57 to 133
- 3 Modern portable spectrodensitometers with ISO 13655 M1 compliance were used to read the papers
- All instruments were standardized according to their manufacturer’s requirements
- All papers were read over a white backing sheet
  - Munsell N925 backing substrate
- The measurements from each instrument were compared in pairs
- ASTM E308 Table 5-9 (D50/2°) was then used to compute the total spectral radiance factor curves exhibit the class shape and range of values for optically brightened white papers
- The 3 reading repeatability for each instrument was:
  - 1: 0.06 \( \Delta E^* \)
  - 2: 0.09 \( \Delta E^* \)
  - 3: 0.10 \( \Delta E^* \)
- While the average differences appear good, the 95% cumulative values are 10X the repeatability.
  - This indicates a distinct difference

Results and Discussion

- The Table shows the contrasts for each of the 3 pairs of instruments
- The 3 reading repeatability for each instrument was:
  - 1 vs 2 is 0.86
  - 1 vs 3 is 0.77
  - 2 vs 3 is 0.64
  - 1 vs 2 is 0.71, 0.69, 0.17
  - 1 vs 3 is 0.50, 0.74, 1.82
  - 2 vs 3 is 0.75, 0.45, 0.08
- The plot at the right shows the ChromaChecker white patch and the pale gray patch.
  - The average \( \Delta E_{00} \) values across the 42 patches:
    - 1 vs 2 is 0.86
    - 1 vs 3 is 0.77
    - 2 vs 3 is 0.64
  - For just the pale gray patch
    - 0.71, 0.69, 0.17
  - For just the white patch
    - 1.50, 0.74, 1.82
  - So the white is clearly more difficult to read

Results and Discussion (cont.)

- The white patch on the ChromaChecker target contains OBA and so would not be suitable.
Results and Discussion (cont.)

- After applying the scaling factors the three instrument contrasts for the ChromaChecker were:
  - \(0.39, 0.49, 0.62\), respectively
  - Thus instruments 1 & 2 and 1 & 3 were improved but 2 & 3 did not change.
  - On the pale gray all differences were 0.0 and on the white patch the \(\Delta E_{ab}\) were reduced to 0.98, 0.67, 1.64 respectively. So the scaling improved the readings
- The unusual behavior of instruments 2 and 3 continue to be an issue, even after rescaling.
- The readings of the papers were then rescaled using the pale gray patch measurements.

Results and Discussion (cont.)

- The table shows the results of the readings of the 50 papers after white scale correction.
- The white scale adjustment removed only about half of the variations.
- Small improvements in some readings can be observed but some contrasts were slightly worse.
- Such behaviors are indicative of a concomitant, untreated systematic variable.

Results and Discussion (cont.)

- Similar contrast comparisons were performed for the M0 and M2 measurement modes.
- Because of the unusual behaviors between instruments 2 and 3 only instruments 1 and 2 are included in this phase.
- The M0 results are slightly worse than the M1 results but not really as bad as expected.
- The M2 results are also slightly worse than the M1 results which is a little surprising.

Statistical Analysis

- Two groups of papers were selected from the main set.
  - Group 1 had 4 papers with similar trade names from the same manufacturer.
  - Group 1 had similar surface, smooth, coated papers.
  - Group 2 had similar CIE Whiteness but different surfaces (coated, uncoated, smooth and matte).

Statistical Analysis (cont.)

- In the MANOVA, both the instrument and the paper substrate were significant contributors to the variance.
- In the report from Wyble, et. al. they noted that as modern spectrophotometers have very high precision (repeatability) it makes even minor differences in the product or instrument identifiable.
  - Here we see that even seemingly minor differences in the instruments are differentiable.
- The question remains as to why the instruments did not improve greatly when the white tile scale was improved and the illumination was simulated to M1.

Discussion

- For completeness, we have included plots of the total spectral radiance factors for each of the two subgroups of papers.
- The plots in the next slide show the 3 measurement conditions, M0, M1, M2 and the eight papers taken from the set of 50.
- The set on the left show the four papers with similar surfaces and coatings while the set on the right show the four with similar optical properties.
  - The M0 mode does a pretty good of removing the emission peak in the left side.
  - The M2 mode does a pretty good job of showing the differences between the papers on the right side.
  - The M0 mode seems to have the most consistency in the emission peaks even through the CIE Whiteness is similar, the papers are actually quite different structurally and also under UV exclusion.
For reference purposes, the ISO \( \Delta b^* \) (\( b^* \) difference between M1 and M2 modes) values for the two paper groups are:
- Group 1 – (10.0, 10.6, 11.4, 11.1)
- Group 2 – (6.2, 9.0, 6.6, 2.4)

The lower \( \Delta b^* \) for paper 43 confirms the results shown in the spectral plots.
- We have seen that using the M2 condition can improve inter-model agreement for papers with different OBA amounts but not for differences in surface structure
- Surface structure impacts the way the incident light flux is reflected and interacts with the geometry of the instrument
- CIE Publication 176 describes the steps required to remove this concomitant variable in the reproducibility of color measurements

All instruments tested demonstrated excellent repeatability
- The M1 process on each instrument resulted in a high level of excitation of the OBA
- The inter-model agreement was improved slightly by adjusting the white scale factor
- The inter-model agreement was not significantly improved for highly fluorescent papers
- The inter-model agreement was improved more significantly for papers with a neutral ink printed on them
- Differences in geometry of the instrument, especially the ratio of influx to efflux area affected the inter-model agreement
- The M1 measurement mode will not resolve all issues related to the agreement between visual and instrumental assessment of print & proofs

Conclusions
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- The M1 process on each instrument resulted in a high level of excitation of the OBA
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