International Color Consortium®

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ICC Recommendations for Color Measurement

Introduction

In order to prepare a useful device profile based on the International Color Consortium's Specification, it is essential to measure color accurately and consistently. This, however, is not a simple task.

CIE, the International Commission on Illumination, has published various recommendations for color measurement, as well as calculation procedures, that can be used for this task. The calculation procedures have been extended in various ISO and ASTM standards. So, users of colorimetry are often confronted with various measurement recommendations which may seem appropriate for their task, each of which could give rise to a different colorimetric result.

It is important, then, that measurement procedures be more uniquely and unambiguously identified, to ensure consistency between users. This White Paper summarizes the issues users should consider when making color measurements for the purpose of constructing ICC profiles, and describes the recommended practices.

Reflecting media

The International Organization for Standardization (ISO) standard ISO 13655 specifies how color measurements and calculations for use in Graphic Technology are to be conducted. ISO 13655 requires that instrument geometry be either 0°/45° or 45°/0° and that all calculations of tristimulus values be achieved using the CIE 1931 standard colorimetric observer, which assumes a 2 degree field of view. ISO also calls for using the CIE D50 illuminant and defines spectral weighting functions derived from this observer and illuminant, which should be used when measurement is made with a spectrophotometer or spectroradiometer in which the spectral sampling interval is coarser than that specified by CIE, namely 1 or 5 nm. It is this specification that is the basis of the measurement procedure specified by ICC.

This specification presents some difficulties when making measurements

intended for use in developing the characterization data required for the construction of ICC profiles, however.

The difficulties arise from the source of illumination used for measurement and the nature of the backing on the sample being measured. For example, ISO 13655 recommends that the source of illumination conform to D50, at least when fluorescence is present in the sample. However, in practice not many instruments actually provide a fully D50 conforming illumination, and few samples are free of fluorescence. Thus, it will be common for measured samples to fluoresce, and the ideal measurement procedure for such conditions is difficult to obtain, as it depends on the illumination used for viewing the sample.

Moreover, many vendors of profiling software differ with ISO's recommendation that black backing be used on measurement samples. These vendors believe white backing produces higher quality profiles. ISO 13655 is under revision as of the writing of this White Paper, and it is likely that changes will be made.

The ISO standard is intended for a very general use, supporting all kinds of color measurement tasks in the graphic arts. ICC believes a more restrictive set of recommendations is desirable for profiling. This White Paper, as a result, seeks to further restrict the conditions defined in ISO 13655 to ensure greater consistency and value in measurements made for profiling purposes.

Fluorescence

Many of the instruments likely to be used in the graphic arts workplace rely on tungsten or tungsten-halogen light sources. Although these lamps emit substantially less ultra-violet (UV) radiation than the D50 norm requires, they will still cause excitation of fluorescing materials in any medium measured.

Instrument manufacturers often offer the opportunity to remove this incident UV radiation. The experience of ICC members suggests that it is best to take this opportunity when making measurements for profiling, even though removing the UV may cause differences from the color perceived in a typical viewing environment.

ICC bases this recommendation on two factors. First, the UV excitation in measurement is likely to be different from one instrument to another, as well as varying from that in the source of illumination used for viewing the print. For this reason the measured stimulus can only be an approximation that may, or may not, produce a color measurement closer to the perceived print color. Given this uncertainty, greater consistency between measurements is likely to be achieved if the UV is excluded.

The other reason arises from the fact that for most printed media the strongest fluorescence is found in the substrate. Furthermore, in a proofing situation, the

proof medium and the print medium may have very different fluorescence. If relative colorimetry is used, which normalizes the data to the substrate, the normalization procedure can introduce unacceptable differences between the ink colors.

Backing

ISO 13655 recommends a black backing when making color measurements for Graphic Arts. The original justification for this was that many prints are printed on both sides of the substrate and using a black backing largely removes the influence of any image on the reverse side of the sheet being measured.

This consideration is highly important to process control on a printing press, but it is rarely relevant in producing profiles. Furthermore, although the ISO 3664 viewing standard requires a black backing when viewing the prints, this is rarely conformed to in practice. Proofs are often made on a substrate that is less transparent than the printed media. If a proof and a one-sided print are being compared, a black backing can introduce a difference between them compared to using a white backing.

The effect of a black backing on a slightly transparent substrate is to reduce the color gamut (including the dynamic range). Although it can be argued that this shouldn't affect the use of a profile in practice, the experience of many ICC members is that it is better to use a white backing for measurements. The general recommendation is to use self-backing, that is, to back a sample with as many additional, unprinted sheets of substrate as are necessary to ensure that no further change in measurement when more are added. However, this can prove difficult in practice, particularly on scanning instruments. Where this is the case, ICC recommends an essentially white medium, ideally of at least 80% reflectance at all wavelengths in the range 380 to 750nm. Ideally, the backing medium should not fluoresce, although since the UV transmission of the print being measured is likely to be small this is probably of limited significance. Materials that meet this requirement include high brightness white ceramic tiles and other surfaces coated with similar colorants.

Polarization Filters

Some measuring instruments allow the user to polarize the incident beam to reduce the effect on the measurement of gloss changes following printing. In such instruments, a cross-polarizer placed in the reflected beam can largely remove the specular reflections that change their characteristics as inks dry. While including this specular component usually provides a better indication of the perceived final result, it can present problems in process control where measurements may be compared between prints where the ink is dry and those where it is still wet to some degree. The use of polarization filters largely

eliminates the measurement differences that can arise between such samples, which can be beneficial in process control.

However, this practice is clearly not desirable for profiling. ICC recommends that polarization filters should be removed, and instruments with polarization which cannot be removed should not be used.

Furthermore, time should be given to ensure that the print is properly dry before making measurements.

Number of measurements

Two significant issues must be addressed when making measurements for the construction of profiles:

- Printer consistency and uniformity, and
- Errors during measurement.

The impact of both factors can be minimized by averaging multiple measurements.

A profile is appropriate for the condition obtained by the calibration of the printer at the time the profiling target was printed. But for many printers, however carefully they are calibrated, some variation will occur over time. The ideal profile should reflect the ‘mean’ of this variation, minimizing its effect by averaging measurements from a number of prints made during a reasonable time period.

Some printers, particularly offset printing presses, can suffer from a lack of uniformity over the sheet. In part, this is caused by the ink coverage in other parts of the sheet. In an attempt to minimize the effect of this variation, some profiling targets are ‘randomized’ to avoid relatively large areas of each ink being localized on the print. If available, ICC recommends the use of randomized targets. When they are not available, or when the potential printed area is much larger than the target, measurements should be made of multiple targets taken from different positions on the sheet, with various orientations of the target. These should be averaged to obtain the data to be used for profiling

Errors may arise during measurement, due to operator error or poor instrument repeatability. To minimize the effect of these errors, ICC recommends the average of a number of measurements of each patch of the target be used when making profiles.

These are recommendations for the “ideal” situation. How many measurements need to be averaged depends on the consistency and/or uniformity of the printer, the instrument repeatability and/or competence of the operator. Prior knowledge of the significance of these factors may permit single measurements to suffice –

however, without that knowledge multiple measurements should be averaged as described here.

Measurement and calculation procedures for transmitting media

The recommendations of ISO 13655 should be followed when measuring transmitting media, with the exception of the source of illumination, which presents the same issues as in the case of reflecting media.

ISO 13655 specifies that the measurement geometry for transmitting media should be either 0°/diffuse or diffuse/0°. If an opal glass diffuser is used, it should conform to that defined in ISO 5-2. The procedure for the calculation of tristimulus values should be the same as for reflecting media, by using the CIE 1931 standard colorimetric observer (2 degree), with the CIE D50 illuminant. The ISO 13655 spectral weighting functions, derived from this observer and illuminant, should be used when the measurement is made with a spectrophotometer or spectroradiometer in which the spectral sampling interval is coarser than that specified by CIE – namely 1 or 5nm.

As for reflecting media, ISO 13655 recommends that the source of illumination should conform to the CIE D50 illuminant. For the reasons previously discussed, ICC recommends a tungsten illuminant, conforming to that in ISO 5-2, with any UV excluded, when making measurements for the production of characterization data for the construction of ICC profiles.

The recommendations as to averaging a number of measurements should be consistent with those recommended for reflection media, except where the image being measured is a commercial input target, in which case the issues of consistency and uniformity are clearly unimportant as the target should not exhibit such problems.

Measurement and calculation procedures for color displays

ISO 13655 does not address measurement of self-luminous sources, such as color displays. However, many other standards or recommendations do so, including CIE Publication 122, IEC 61966 (parts 3 to 5), and the ASTM standards E1336 and E1455. These specifications recommend measurement procedures as well as measurement instrument characteristics. Among them they cover measurements obtained with both spectroradiometers and tristimulus colorimeters. Measurements of displays should be consistent with the recommendations made in whichever of these standards is appropriate to the type of display and/or measurement device used. If the user can assume that the measurement instrument used is in conformance with these standards, then the user need address only a small number of issues.

Care should be taken when making measurements to ensure that the sampling frequency, or integration time, of the instrument used is synchronized with the frequency of scanning of the display. If not, at least 10 measurements should be taken and averaged.

Although the use of telespectroradiometers or telecolorimeters for measurement from the viewer position is often advantageous, they are not in common use among those building profiles. ICC recommends that they be used whenever possible, as they include allowance for any veiling glare present, and therefore provide an accurate representation of the color as perceived by the viewer. Where such instruments are not available, and measurements are made in contact with the face of the display, the ambient light should be measured at the viewer position and used to correct the measurement data obtained. If this is not possible, the contact measurements should be corrected by assuming a veiling glare of 1cd/m^2. However, users should be aware that this may not be correct for their specific viewing conditions, which is why the first or second of the above methods are preferred.

Where profile makers allow users to specify the ambient illumination as part of the input for profile construction, no other data correction is required. When this is not the case, the user will have to correct the data prior to building the profile.

Measurements of the display should be made to ensure acceptable levels of constant channel chromaticity, spatial uniformity, internal flare and channel independence. Those exhibiting poor uniformity or high levels of internal flare should be avoided, or care taken to average measurements made with varying image surround and/or position. For displays with inconsistent channel chromaticities, or poor channel independence, profiles should be based on n-component LUT rather than three-component matrix.

When spectral data is obtained during measurement, the CIE 1931 standard colorimetric observer (2 degree) should be used for the calculation of tristimulus values.

Averaging measurements to minimize the effects from poor synchronization of the scanning frequencies and measured sampling intervals, and poor uniformity or internal flare has already been described. Averaging to avoid measurement errors should also be undertaken, particularly where multiple measurements are not undertaken because of good synchronization between display scanning frequency and measurement sampling interval.

Summary of the recommendations

The recommended measurement conditions and procedures described above are summarized below:

- Reflectance and transmittance measurements should conform to ISO 13655 except that no UV should be included in the incident beam, and for reflectance measurements a white or self-backing is recommended.

- For reflectance instruments the use of polarizing optics should be avoided.

- For displays measurement instruments should be consistent with the recommendation of CIE Publication 122, IEC 61966 (parts 3 to 5), or the ASTM standards E1336 and E1455. Measurement should be made with a telescopic instrument at the viewer position, but where this is not possible, and the measurement is made using an instrument in contact with the face of the display, the veiling glare at the viewer position should be measured with a colorimeter or photometer. If this cannot be done a veiling glare of $1cd/m^2$ should be assumed. When measurement is made in contact, the veiling glare should be used to correct the data prior to profile construction, unless profile building software allows this as a separate input. Multiple measurements should be made to minimize the effect of poor synchronization between the display scanning frequency and measurement integration time. For displays with inconsistent channel chromaticities, or poor channel independence, profiles should be based on n-component LUT rather than three-component matrix.

- Multiple measurements of each patch should be averaged. The extent of this should be consistent with the uniformity and/or temporal consistency of the device, and temporal consistency of the measurement instrument and/or operator.