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Analytica Chimica Acta 380 (1999) 285–288

ANALYTICA CHIMICA ACTA

Comparison of CIE chromaticity values

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Received 6 July 1998; accepted 14 July 1998

Abstract

A chromaticity comparison took place in order to fulfil the requirements of the mutual recognition agreement (MRA) between the South African National Metrology Laboratory (CSIR/NML) and the Taiwanese National Measurement Laboratory (ITRI/CMS). The absolute spectral reflectance of each standard of a set of 12 BCRL Series II standards was measured on spectrophotometers for 0°/d geometry by a comparison method with a white reference standard. The CIE chromaticity values were calculated under the conditions of Illuminants A, C and D65 for a 2° observer. Good agreement was found in general between the results of CSIR/NML and ITRI/CMS within the respective uncertainty calculations.

Keywords: Chromaticity coordinates; Spectral reflectance; BCRL series II colour standards; CIE chromaticity coordinates

1. Introduction

The strong trade relationship, and agreements between national accreditation and regulatory bodies, between South Africa and Taiwan, required the determination and documentation of equivalence of national measuring standards. As a result, a mutual recognition of national measuring standards agreement (MRA) was signed by CSIR/NML and ITRI/CMS on 4 February 1991. The signatories agreed in principle to recognise the degree of equivalence of national measuring standards and also the validity of calibration certificates issued by the two participating laboratories.

In order to fulfil the requirements of the MRA, a timetable for the exchange of measurement values via comparisons and technical expertise via interlaboratory visits was established. The first series of comparisons was conducted in 1994 and included the fields of temperature, acoustics, pressure and mass. The 1996 comparison on CIE chromaticity values formed part of the second series of comparisons which included the fields of dimension, acoustics, inductance and photometry.

2. Experimental

2.1. Requirements

Each laboratory was requested to measure the spectral reflectance of each standard of a set of 12 BCRL Series II colour standards on a spectrophotometer for 0°/d geometry by a comparison method with

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0003-2670/99/$ – see front matter
PII: S0003-2670(98)00526-1

an opal glass white standard. Furthermore, the *x* and *y* CIE chromaticity values had to be calculated under the conditions of illuminants A, C and D65 with a 2° observer.

2.2. Implementation

2.2.1. CSIR/NML

The spectral reflectance for the wavelength region 380–780 nm was measured in steps of 5 nm on a double beam, double dispersion spectrophotometer for the 0°/d geometry. The spectral reflectance measurements were traceable to the South African national measuring standards of light by an opal glass reflectance standard (NPL calibration number AU87) calibrated by the National Physical Laboratory, UK (NPL). Reflectance measurements were taken at three different positions on each standard. The *x* and *y* CIE chromaticity values were calculated under the condition of illuminants A, C and D65 for each position and average values for *x* and *y* were taken for each tile. The measurements were carried out at an ambient temperature of 24±2°C and at a relative humidity of 40±20% RH.

2.2.2. ITRI/CMS

The spectral reflectance of each colour standard was measured for the wavelength region 400–750 nm in steps of 10 nm on a spectrophotometer for the 0°/d geometry. The spectral reflectance measurements were traceable to the national measuring standards of Taiwan by the opal glass reflectance standard (NPL certificate number QO03/5/95/003D) calibrated by the National Physical Laboratory, UK (NPL). The *x* and *y* CIE chromaticity values were calculated under the conditions of illuminants A, C and D65. The measurements were carried out at an ambient temperature of 23±1.5°C and at a relative humidity of 45±10% RH.

3. Results

3.1. CSIR/NML

The *x* and *y* chromaticity values as calculated by the CSIR/NML for illuminants A, C and D65 are given in Tables 1–3, respectively [1].

Table 1
The CSIR/NML *x* and *y* CIE chromaticity values for illuminant A and 2° observer

Chromaticity values	*x*	*y*
Pale grey	0.4475	0.4081
Mid grey	0.4468	0.4077
Difference grey	0.4461	0.4137
Deep grey	0.4490	0.4097
Deep pink	0.5569	0.3579
Red	0.6606	0.3259
Orange	0.5881	0.3933
Bright yellow	0.5238	0.4530
Green	0.3785	0.4779
Difference green	0.3846	0.4826
Cyan	0.2929	0.3650
Deep blue	0.2906	0.2282

Table 2
The CSIR/NML *x* and *y* CIE chromaticity values for illuminant C and 2° observer

Chromaticity values	*x*	*y*
Pale grey	0.3103	0.3175
Mid grey	0.3094	0.3169
Difference grey	0.3111	0.3258
Deep grey	0.3121	0.3203
Deep pink	0.4096	0.2962
Red	0.6076	0.3282
Orange	0.5278	0.3971
Bright yellow	0.4528	0.4831
Green	0.2703	0.4071
Difference green	0.2776	0.4195
Cyan	0.1965	0.2261
Deep blue	0.1929	0.1082

Table 3
The CSIR/NML *x* and *y* CIE chromaticity values for illuminant D65 and 2° observer

Chromaticity values	*x*	*y*
Pale grey	0.3129	0.3304
Mid grey	0.3120	0.3298
Difference grey	0.3135	0.3389
Deep grey	0.3146	0.3332
Deep pink	0.4136	0.3055
Red	0.6077	0.3314
Orange	0.5292	0.3997
Bright yellow	0.4496	0.4885
Green	0.2700	0.4221
Difference green	0.2769	0.4341
Cyan	0.1977	0.2407
Deep blue	0.1910	0.1000

Table 4
The ITRI/CMS x and y CIE chromaticity values for illuminant A and 2° observer

Chromaticity values	x	y
Pale grey	0.4473	0.4083
Mid grey	0.4466	0.4080
Difference grey	0.4461	0.4138
Deep grey	0.4493	0.4097
Deep pink	0.5573	0.3585
Red	0.6596	0.3271
Orange	0.5882	0.3940
Bright yellow	0.5233	0.4528
Green	0.3816	0.4776
Difference green	0.3880	0.4817
Cyan	0.2936	0.3651
Deep blue	0.2896	0.2269

Table 5
The ITRI/CMS x and y CIE chromaticity values for illuminant C and 2° observer

Chromaticity values	x	y
Pale grey	0.3101	0.3177
Mid grey	0.3093	0.3171
Difference grey	0.3111	0.3259
Deep grey	0.3123	0.3206
Deep pink	0.4108	0.2976
Red	0.6075	0.3297
Orange	0.5291	0.3992
Bright yellow	0.4517	0.4822
Green	0.2733	0.4083
Difference green	0.2807	0.4199
Cyan	0.1969	0.2261
Deep blue	0.1905	0.0995

The uncertainty in both the x and y CIE chromaticity values was ±0.001.

The reported uncertainty of measurement was calculated and expressed in accordance with the BIPM, IEC, ISO, IUPAP, OIML document entitled "Guide to the Expression of Uncertainty in Measurement" (International Organisation for Standardisation, Geneva, Switzerland, 1993).

The reported uncertainty of measurement is based on a standard uncertainty multiplied by a coverage factor of k=2, which provides a level of confidence of approximately 95%.

3.2. ITRI/CMS

The x and y chromaticity values as calculated by the ITRI/CMS for illuminants A, C and D65 are given in Tables 4–6, respectively [1].

The uncertainty of measurement for both x and y chromaticity values was ±0.0040 for the deep blue and red colour standards and ±0.0022 for the remaining colour standards. The uncertainties were estimated in terms of 95% confidence limits.

4. Discussion

The results of the comparison are given in terms of E_n values. An E_n value between the limits ±1 indicates a good agreement between the CSIR/NML and ITRI/CMS x or y chromaticity values.

Table 6
The ITRI/CMS x and y CIE chromaticity values for illuminant D65 and 2° observer

Chromaticity values	x	y
Pale grey	0.3127	0.3306
Mid grey	0.3119	0.3300
Difference grey	0.3135	0.3390
Deep grey	0.3148	0.3335
Deep pink	0.4148	0.3068
Red	0.6076	0.3328
Orange	0.5304	0.4018
Bright yellow	0.4485	0.4877
Green	0.2728	0.4231
Difference green	0.2801	0.4343
Cyan	0.1980	0.2406
Deep blue	0.1923	0.1077

The E_n values are calculated as follows:

$$E_n = \frac{\mathrm{CMS}_{\mathrm{result}} - \mathrm{NML}_{\mathrm{result}}}{\sqrt{(U_{\mathrm{CMS}})^2 + (U_{\mathrm{NML}})^2}},$$

where U_{CMS} and U_{NML} are the uncertainties of the chromaticity values of ITRI/CMS and CSIR/NML, respectively.

The x chromaticity values of the green and difference green standards calculated by ITRI/CMS differ appreciably from those calculated by CSIR/NML for illuminant conditions A, C and D65 (Figs. 1–3). The cause of these differences could be attributed to different definitions for illuminant A, C and D65 as well as differences in measurement.

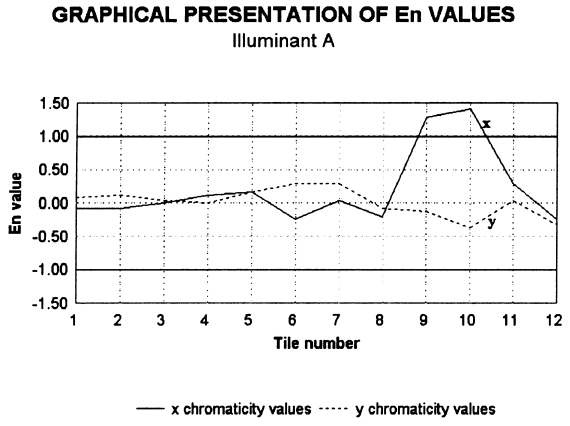

Fig. 1. A plot of the E_n values for illuminant A indicates a lack of agreement of x chromaticity values for tiles 9 (green) and 10 (difference green).

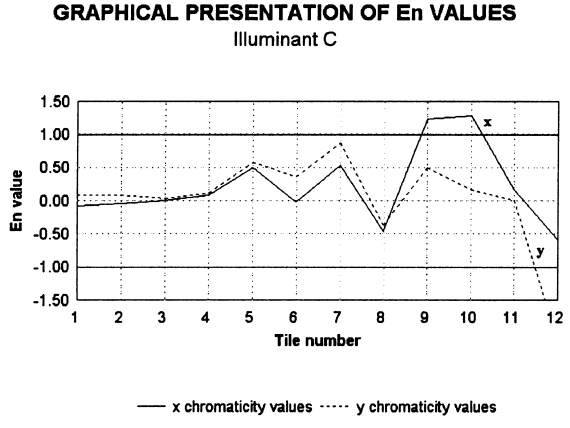

Fig. 2. A plot of the E_n values for illuminant C indicates a lack of agreement of x chromaticity values for tiles 9 (green) and 10 (difference green) and of the y chromaticity value for tile 12 (deep blue).

The y chromaticity value of the deep blue standard calculated by ITRI/CMS also differs appreciably from those calculated by CSIR/NML for illuminant conditions C and D65. The difference could be attributed to the differences in the longer and shorter wavelength regions of the visible spectrum used for spectral reflectance measurements.

Fairchild and Grum [2] reported that the orange, bright yellow and red BCRA standards all exhibit

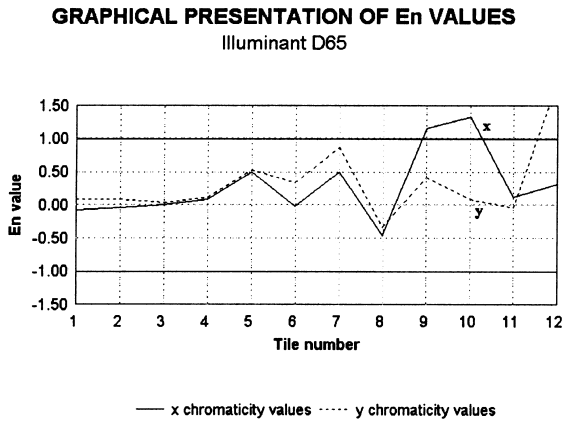

Fig. 3. A plot of the E_n values for illuminant D65 indicates a lack of agreement of x chromaticity values for tiles 9 (green) and 10 (difference green) and of the y chromaticity value for tile 12 (deep blue).

appreciable thermochromism. This effect has not been investigated but may account for the larger differences in x and y chromaticity values for standards 6, 7 and 8, although there are sufficient agreements in E_n values.

5. Conclusion

In spite of the difference in chromaticity values for the green, difference green and deep blue colour standards, good agreement was found between the results of CSIR/NML and ITRI/CMS within the respective uncertainty calculations. New methods to improve the uncertainty estimations will be investigated, which may improve the agreement between the chromaticity values. The measurement of the x and y chromaticity values by a third national metrology laboratory will yield valuable insight and might explain some of the differences.

References

[1] N. van Tonder, Report on chromaticity value intercomparison between CSIR/NML and ITRI/CMS, NML Report no. OR-5005, January 1997.

[2] M.D. Fairchild, F. Grum, Thermochromism of ceramic reference tiles, Appl. Opt. 24 (1985) 3432–3433.