IL NUOVO CIMENTO **47 C** (2024) 322
DOI 10.1393/ncc/i2024-24322-6

Communications: SIF Congress 2023

Color specification: Comparison between contact and non-contact measurement methodologies

A. Incardona, G. Paladini, G. Stella and Anna M. Gueli

Dipartimento di Fisica e Astronomia "Ettore Majorana", Università degli Studi di Catania Via S. Sofia, 64, 95123 Catania, Italy

received 19 February 2024

Summary. — A methodological study regarding color specification through both contact and non-contact techniques is presented. The principal aim is the evaluation of chromatic differences obtained by the two methods varying the experimental parameters in order to quantify their influence. The results obtained for cardboard cubes of seven hues, red (R), green (G), blue (B), yellow (Y), black (K), white (W) and grey (Gy), considering CIELAB 1976 coordinates, are presented. The color differences were evaluated through the ΔE values and in the chromatic plane using Δa^* and Δb^* differences. The study was performed using a Konica Minolta® CM-2600d spectrophotometer and a Konica Minolta CS-1000A spectroradiometer for, respectively, contact and non-contact measurements under different experimental conditions. Different illuminants (D65, A and F11) and both the 2° and 10° CIE standard observers were selected. In both cases the circular measuring area used was 11 mm in diameter. The results obtained show good agreement except for the extreme achromatic black and white cubes. The best agreement was obtained when illuminant A is used for the colorimetric calculation. The obtained results provide novel and useful insights into the behavior of the color coordinates according to the chosen experimental conditions.

1. – Introduction

Color measurements are based on the correspondence between chromatic sensations and the light radiation that stimulates them, using International Commission on Illumination (CIE) standards. This involves the relative power distribution of the illuminant, the spectral reflectance of the sample, and the response curves of the cones in the human eye to obtain XYZ coordinates. These can be transformed into CIELab coordinates (L^*, a^*, b^*), representing brightness, green-red component and blue-yellow component, offering an objective standardization of human color perception [1]. Spectrophotometers and spectroradiometers are instrumentations able to measure spectral quantities, providing a detailed overview of the spectral distribution of light. In particular, spectrophotometers have a closed system with an integrating sphere, collecting diffused light, while spectroradiometers acquire a portion of diffused light in an open solid angle, influenced by external colorimetric contributions [2]. The spectrophotometric method is commonly used for color measurements in conservation and restoration settings, where color fidelity is of primary importance due to its high accuracy and repeatability [3-7]. On the other hand, the spectroradiometer comes closest to the ideal color viewing condition and also allows for the evaluation of distortions due to colorimetric distribution outside the measurement point [8-10]. In this context, the present work reports the results regarding color specification achieved through both contact and non-contact methodologies obtained for cardboard cubes of seven hues making use of a spectrophotometer and a spectroradiometer for contact and non-contact measurements, using different parameters.

2. – Materials and methods

Colorimetric measurements were conducted on seven monochromatic cardboard cubes, each with a side length of 7 cm, representing different hues. These hues include: black (B), grey (Gy), white (W), red (R), green (G), blue (B) and yellow (Y). The cardboard cube colors were selected based on the four hues (red, green, yellow, and blue) used to define the a^* and b^* color coordinates in the CIELAB color space (x- and y-axes) [11]. Additionally, three achromatic colors (black, grey, and white) were included, accounting for the minimum, intermediate, and maximum values of the L^* coordinate (z-axis). Contact colour measurements were conducted using a Konica Minolta® CM-2600d spectrophotometer operating in the 360–740 nm spectral range with a 10 nm acquisition step. The measurement geometry followed the d/8 configuration, and the measurement area had a diameter of 11 mm (MAV condition). In particular, the specular component was excluded and UV component was considered. For color specification three different illuminants —D65, A, and F11— were used, along with two different standard observers (2° and 10°).

The lightness scale adjustment was performed using a white calibrated plate (CM-A145) and a black box (Zero-Calibration Box CM-A32 Minolta) were employed as targets for the maximum and minimum values. The collected data were obtained using the dedicated software SpectraMagic®. Data analysis was carried out using Origin® software (OriginPro 2021). Non-contact color measurements were conducted using a Konica Minolta CS-1000A spectroradiometer operating in the 380–780 nm spectral range with a 1 nm acquisition step. The measurement geometry followed the 45/0/45 configuration, fixing the distance between the detector and the object to obtain a measurement area with a diameter of 11 mm. An external illuminant (type A) was used to obtain the SRF% (spectral reflectance factor). To perform the scale adjustment, a white calibration plate (CS-A5) was used. For color specification, three different CIE standard illuminants —namely D65, A, and F11— and two different standard observers (2°/10°) were employed. The colorimetric differences were calculated in terms of ΔE^*_{ab} using the following equation:

$$(1) \qquad \Delta E^*_{ab} = \sqrt{(L^*_{cont} - L^*_{non-cont})^2 + (a^*_{cont} - a^*_{non-cont})^2 + (b^*_{cont} - b^*_{non-cont})^2},$$

where L^*_{cont}, a^*_{cont} and b^*_{cont} refers to the set of colorimetric coordinates obtained using the contact technique, while $L^*_{non-cont}$, $a^*_{non-cont}$ and $b^*_{non-cont}$ refers to those obtained using the non-contact technique.

3. – Results and discussion

In order to validate the methodological approach, the first step involves the comparison of the colorimetric results obtained on the white CM-A145 and CS-A5 plates in terms of ΔE^*_{ab}. These plates are characterized by a diffuse light behaviour of isotropic type and % reflectance close to 100% in the whole visible spectrum. By varying both the CIE standard illuminants (D65, A, F11) and the standard observer (2°, 10°), a value of $\Delta E^*_{ab} < 1$ was always obtained. In the next phase, these colorimetric differences were calculated (fig. 1) from black (K), grey (Gy), white (W), red (R), green (G), blue (B) and yellow (Y) hue cubes, using eq. (1) and changing the observer (2° and 10°).

Figure 1 reports the measured colorimetric differences both when varying the CIE standard illuminant and when varying the standard observer. In particular, within the experimental errors, in all cases a $\Delta E^*_{ab} < 3$ was observed with the only exception of the black and white sample. In the case of the black sample, the differences are undoubtedly due to both the different adjustment procedures for the two methodologies and the low photon flux detected by the spectroradiometer in the non-contact method, considering that black is a highly absorbent sample. Indeed, while the spectrophotometer methodology expect adjustment with both white and black standards, the spectroradiometer only adjusts with white plate, assigning zero electronic value to black. Consequently, in the spectrophotometer case (contact approach), the color specification of black is significantly influenced by the different adjustment procedures used. In the case of white, the difference is likely due to the presence of a fluorescent component, which is only partially detected in the non-contact method. While the contact method employs an integrating sphere that collects the entire scattered light, the non-contact method gathers only a portion of the scattered light from a solid angle of 1°. However, the evaluation in terms of ΔE^*_{ab} does not give any information on the direction of the colour change in terms of a^* and b^*. Considering the similarity of results obtained above when varying the standard observer, the colour differences in terms of $\Delta a^* = (a^*_{cont} - a^*_{non-cont})$ and $\Delta b^* = (b^*_{cont} - b^*_{non-cont})$ using 10° standard observer and varying the CIE standard illuminant (D65, A and F11), were considered (fig. 2).

Figure 2 shows the chromatic differences for a^* and b^* coordinates calculated using contact methodology data as reference. It is in particular possibile to observe that for the red sample the value of a^* and b^* decreases for all illuminants. This indicates a change in colour saturation and not a change in perceived hue compared to the contact measurement; for the green, yellow, black and grey samples there is an increase in the value of a^* and a decrease in the value of b^*, implying a shift in perceived hue; for the

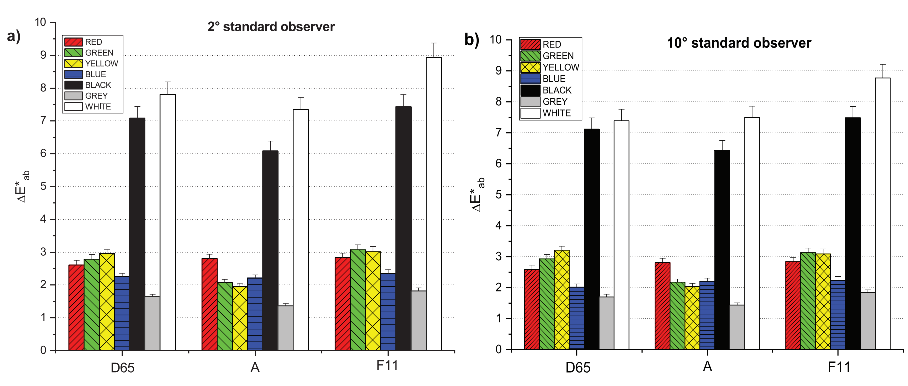

Fig. 1. – The colorimetric differences ΔE^*_{ab}, changing the CIE standard illuminants (D65, A, F11), observed on the coloured samples calculated using eq. (1) at (a) 2° and (b) 10° standard observer.

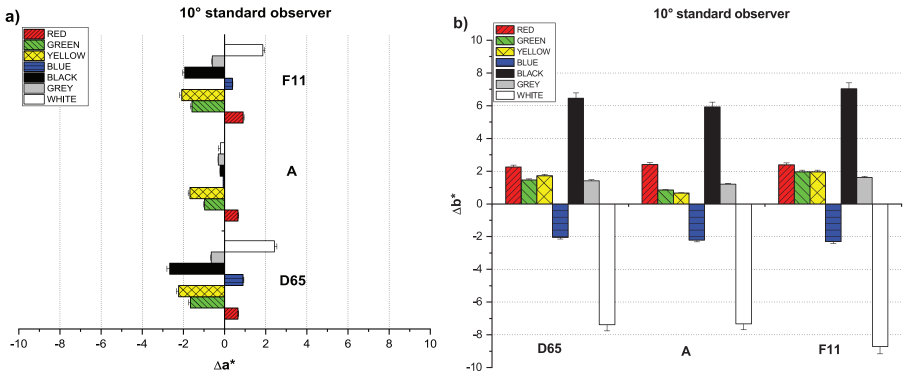

Fig. 2. – The colorimetric differences Δa^* (a) and Δb^* (b), changing the CIE standard illuminants (D65, A, F11) at 10° standard observer, calculated on the coloured samples.

blue sample we can observe an increase in a^* values and a decrease in b^* values when using the D65 and F11 CIE standard illuminant. In this case there is a hue shift in the colour perception. On the other hand, in the case of the CIE standard illuminant A, an increase in both a^* and b^* coordinates can be recognized, indicating an increase in saturation; for the white sample, in the case of the CIE standard illuminant D65 and A an increase in saturation can be measured, while in the case of the illuminant F11 a change in saturation can be observed; using the CIE standard illuminant A, the smaller colorimetric distance between contact and non-contact measurements was obtained.

* * *

The research activity is part of the project CLEAR supported by Piano di incentivi per la ricerca di Ateneo 2020/2022 (Pia.ce.ri), Linea di Intervento 2 of the University of Catania.

REFERENCES

[1] Oleari C., *Standard Colorimetry: Definitions, Algorithms and Software* (John Wiley & Sons) 2016.
[2] CIE, CIE Publication No. 38 *Radiometric and photometric characteristics of materials and their measurement* (1977).
[3] Gueli A. M. *et al.*, *Instruments*, **3** (2019) 42.
[4] Incardona A. *et al.*, *Color speciication for color rendering*, in *Proceedings of the 2022 IMEKO TC4 International Conference on Metrology for Archaeology and Cultural Heritage (IMEKO)*, 2023, pp. 374–377.
[5] Allegra D. *et al.*, *J. Phys.: Conf. Ser.*, **2204** (2022) 012057.
[6] Simonot L. and Elias M., *Color Res. Appl.*, **28** (2003) 45.
[7] Lorusso S. *et al.*, *Conserv. Sci. Cult. Herit.*, **7** (2007) 187.
[8] Trigona C. *et al.*, *Sensors*, **24** (2024) 1278.
[9] Vazquez D. *et al.*, *Proceedings of the Denkmäler 3D Conference*, edited by A. Bentkowska-Kafel and O. Murphy, in *Proceeding of the Denkmäler 3D Conference* (Cosh) 2014, pp. 1–6.
[10] Fedutina M. *et al.*, *Proceedings of the Color and Imaging Conference* (IS&T) 2011, pp. 2–7.
[11] Commission Internationale de l'Eclairage, *Colorimetria*, 4th edition (Ufficio Centrale CIE, Vienna) 2018.