

Software with Visual Phenomena, Tests and Standard Colorimetric Computations for Didactics and Laboratory

Gabriele Simone¹, Claudio Oleari²;

1: Gjøvik University College, Gjøvik, Norway

2: Physics Department of Parma University – I43100 Parma, Italy

Abstract

A complete software on standard colorimetry, named “Colour & Colorimetry”, has been developed for laboratory computations and didactics. This software will be part of a forthcoming book on colorimetry (ref. 1). Today, it is successfully used at the University of Parma and soon will be used in the European ERASMUS Master Program, entitled “Color in Informatics and MEDIA Technology” (CIMET). The completeness and practical effectiveness of the 2nd edition of this software induces us to present it at the Sixteenth Color Imaging Conference.

Software “Colour & Colorimetry”

The main purpose of the software “Colour & Colorimetry” is:

- support teachers and students in learning basic and advanced concepts about colorimetry
- provide an useful tool for computations to the lab technician.

The software presents 27 toolboxes divided in the following 9 categories:

1. Monitor
2. Colour-Vision test
3. Visual contrast phenomena
4. Colour atlases
5. Tristimulus and cone activation
6. Colorimetry
7. Reference illuminant spectra
8. Colour synthesis
9. Tools

Each toolbox can be open by a simple main graphic interface.

Monitor

Monitor setup

This toolbox allows the user to setup the chromaticities of the 3 primary and white lights in order to have a colorimetric reproduction of the colors.

The RGB primaries are typical of the monitor used, therefore an “ad hoc” build matrix allows the transformation between the monitor RGB reference frame and the standard XYZ reference proper of the standard observers.

Visual evaluation of the gamma

The color management in a cathode-ray tube (CRT) monitor needs the knowledge of the emitted luminance as function of the signal driving the electron guns of the CRT. This function is evaluated by visual comparison of two contiguous squares with the same primary color, Red, Green and Blue. One square is emitting light in its entire surface, while the second one emits only at alternate lines. In correspondence to the fixed luminance of this second square, the signal driving the first square is modified until it appears equal to the second one (the square has to be seen at a distance such that the alternate lines are undistinguishable).

Once the averaged luminances are matched, the luminous lines of the second square have half luminance equal to the double luminance of the square, because the emitting areas of the two squares are in ratio 1 to 2. In this way a correspondence between signals (number of bits in the software and voltage in the CRT) and luminances is defined. A program evaluates the best parameters of the unknown fitting line.

Colour-Vision test

Colour-Vision test

This test diagnoses the anomalies of the visual system of the observer. At the end, the observer may be:

- normal trichromat
- anomalous trichromat: protanomalous, deuteranomalous or tritanomalous
- dichromat: protanope, deuteranope or tritanope.

This test considers 10 color patches, equiluminant for the standard observer CIE 1931, and is organized in two steps proposing:

- the matching of the luminances of the 10 samples perceived by the observer, changing the luminances until minimum is the distinction of the borders between samples and surround (*minimum distinct border technique*);
- the chromatic ordering of the 10 color samples, previously matched in luminosity, starting from a given samples and choosing the closest color sample among the not yet chosen samples until the whole sample set is exhaust.

Diagnosis comes out by comparing the results of the considered observer and the standard observer.

Visual contrast phenomena

Luminance, contrast and crispening

This toolbox (Fig. 1) shows two equal sets of rectangles in equal luminance scales, from the black to the white of the monitor. The difference between the two sets is produced by the proximal field, which originally is set black in the left set, while the right rectangles are mutually touching. The consequence is that:

- the left rectangles appear internally uniform
- the right rectangles show a brightness increasing from top to bottom.

The observer can isolate a left rectangle by using two uniform and equal cards and so verify the internal uniformity of the stimuli. It appears that the left and right rectangles have equal luminance.

The observer can modify the luminance of the left proximal field and, the luminance crispening appears: the rectangles brighter that the proximal field appears with increased brightness while those darker appear with lowered brightness. The effect is particularly evident during the continuous modification of the proximal field.

The observer can modify the hue of the rectangles and verify that the phenomenon is hue independent.

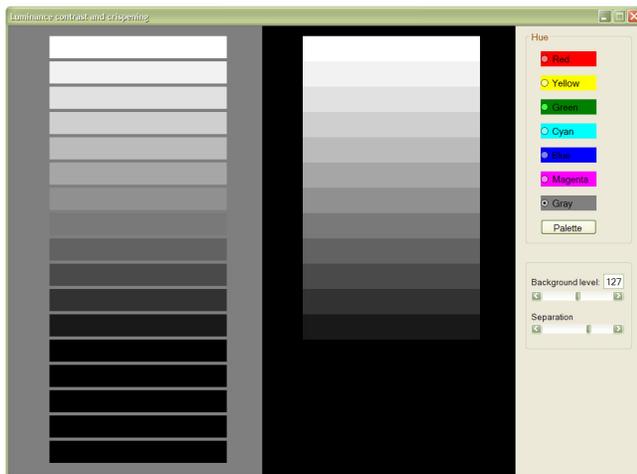


Figure 1. Luminance contrast and crispening. In the right side panels crispening phenomena is visible. Rectangles look bent and their luminosity look to decrease from the bottom to the top. A comparison with rectangles in left side shows clearly that they are uniform colored.

Luminance contrast in colour scales

This toolbox shows a matrix of color samples, in which any row has defined hue and the brightness increases from right to left. The color samples can be seen in four different ways with different appearances:

	Visual mode	Appearance
1	The color samples are separated by a black line vertically and horizontally	The color samples appear internally uniform
2	No black line separate the color samples	The color samples appear internally non-uniform and bended as a cylindrical surface with vertical axis
3	Only the rows are separated by black lines	The color samples appear internally non-uniform and bended as a cylindrical surface with vertical axis
4	The columns are separated by black lines	The color samples appear internally uniform

The experiment shows only the dependence of the brightness on the luminance of the contiguous fields.

Luminance and chromatic scales

This toolbox shows an open ring, which proximal field is constituted by two contiguous fields with different colors and with the separation line between the two ends of the open ring. The observer can continuously modify the contents of the primary colors, Red, Green and Blue, which additively constitute the color of the open ring. Generally, the color of the open ring appears different in the two parts, going from one color to the other continuously. The difference of the two parts of the open ring can be a luminance difference or/and a chromatic difference. This is the case of simultaneous contrast.

Colour atlases

Munsell atlas

This toolbox shows the whole Munsell system of colors renoted by Newhall, Nickerson e Judd (ref. 2) under the standard C illuminant and for the standard colorimetric observer CIE 1931.

Colors are shown according to the Munsell's coordinate system, i.e. tables with color samples with equal Hue and ordered in any table with the Chroma in abscissa and the Value in ordinate. The colors represented by an empty rectangle cannot be reproduced with the monitor that we are using.

The observer chooses the page of the atlas.

The comparison with the DIN system shows the deep difference between Chroma and Saturation.

DIN atlas

This toolbox shows the whole DIN atlas under the illuminant C.

Colors are presented in the DIN coordinate system, i.e. in tables at constant hue T (*Farbton*) with in abscissa the saturation S (*Sättigung*) and in ordinate the relative darkness D (*Dunkelstufe*).

The color samples represented by an empty rectangle cannot be represented by the monitor used.

The saturation S is defined according to uniform perceptible scales on the CIE 1931 chromaticity diagram at fixed defined D . Because the resolution of a chromatic scale increases linearly with the linear decreasing of the relative darkness D , the color difference between contiguous samples at fixed T and S changes linearly with D . The difference between Chroma and Saturation appears clearly by comparing the DIN and the Munsell's system. The considered observer is the CIE 1931.

OSA atlas

This toolbox presents different plane sections of the OSA-UCS space. The color samples are lit by the D65 illuminant. Empty rectangles represent color not reproducible by the monitor used.

The observer is the CIE 1964.

The section planes different from those at constant lightness are partially overlapping showing simultaneous luminance and chromatic contrast.

CIELAB-CIELUV

This Reading a three-dimensional view of the CIELAB and CIELUV spaces is difficult, therefore we propose a representation of sheets based on:

- constant hue angle plane (h_{ab})
 - constant lightness planes (L^*)
- Only the colors reproducible by the monitor in use are represented.

The user chooses:

- the observer
- the section of the cylindrical coordinates at constant hue angle
- the illuminant
- the way to represent contiguous colors, with or without separating line (in this way the simultaneous chromatic contrast appears in the rows and the simultaneous luminance contrast between lines).

Tristimulus and cone activation

Tristimulus and cone activation

The program considers the spectral reflectance factors of 5 Munsell samples 5R/7/8, 5Y/7/8, 5G/7/8, 5B/7/8, 5P/7/8 with equal value $V = 7$, equal chroma $C = 8$ and different hues under different CIE (standard and recommended) illuminants. The program considers:

- the spectral power distributions of the illuminants considered
- the spectral reflectance factors of the 5 Munsell samples
- the spectral sensibilities of the three kind of cones

then combines these three factors producing the cone activations. This representation is a simulation of the cone activation process with the reproduction of the color. The color

non colorimetrically reproducible by the monitor used are given by simulation.

Colorimetry

CIE colour specification

This toolbox computes the color specification of light sources whose spectral power distribution is known and recorded on file. The file must be an ASCII file, named with the extension .TXT, and written in defined format.

This program computes also the color specification of non self-luminous colors, whose spectral reflectance factor is known, written and recorded on an ASCII file according to a defined format. In this case, the illuminant must be chosen.

Both kinds of computation need the choice of an observer (CIE '31, CIE '64 or VOS).

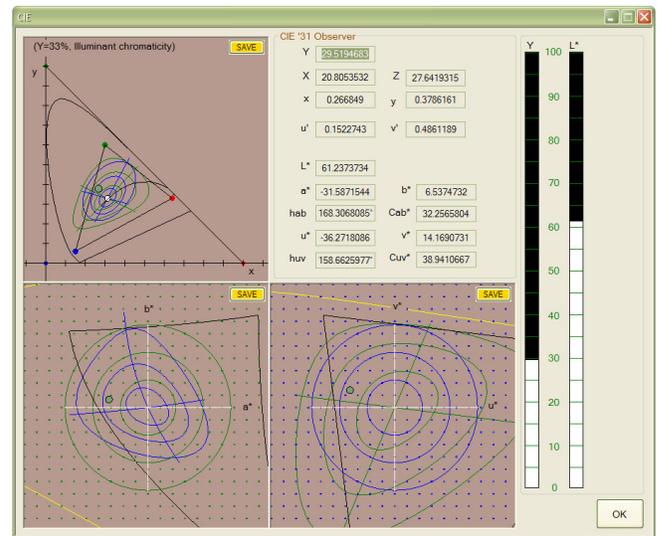


Figure 2. CIE color specification. References visualization given a color stimulus.

CIE systems

This toolbox makes the transformations between all the colorimetric systems of CIE, with regard to all the observers, the illuminants (standard and recommended): (X, Y, Z) , (Y, x, y) , (L^*, a^*, b^*) , (L^*, h_{ab}, C_{ab}^*) , (L^*, u^*, v^*) , (L^*, h_{uv}, C_{uv}^*) . Moreover the considered color is reproduced on the monitor.

Chromaticity diagrams

This toolbox considers the 11 most meaningful chromaticity diagrams related to the CIE 1931 observer. It is possible to plot on the chosen diagram the MacAdam ellipses, the Planckian locus, the triangle of the RGB chromaticities of the used monitor. The xy net of the CIE 1931 diagram is reproduced on all the considered diagrams for a comparison.

Vos observer

The VOS's observer has been obtained from the CIE 1931 one by correcting a systematic error present in the short

wavelength region. This observer is mainly used by physiologists and is generally represented in the fundamental reference frame (L, M, S). The transformation between the different coordinate systems is made (X', Y', Z') , (Y', x', y') , (L, M, S) , (Y', l, m) ; these coordinates are plotted and the color is reproduced on the monitor.

Dominant wavelength and purity

This toolbox computes the dominant wavelength and the corresponding complementary wavelength of a color.

The user chooses:

- the observer
- the chromaticity of the color stimulus
- the chromaticity of the neutral source.

The complete color specification is obtained by computing, in addition to the dominant wavelength, the *excitation purity* or the *colorimetric purity*. The excitation purity is defined on the (x, y) CIE diagram, while the colorimetric purity on the luminances.

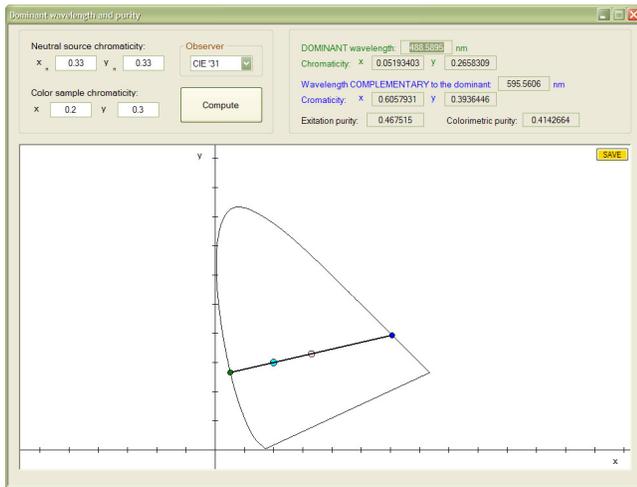


Figure 3. Dominant wavelength and purity. Calculus given a color stimulus with chromaticity $x=0.2$ $y=0.3$ and a light source with chromaticity $x=0.33$ $y=0.33$ (neutral stimulus).

Tristimulus space transformation

Given the chromaticities of the 3 primary lights (A, B, C) and the neutral stimulus, this toolbox computes the conversion matrix between ABC and XYZ CIE reference frames.

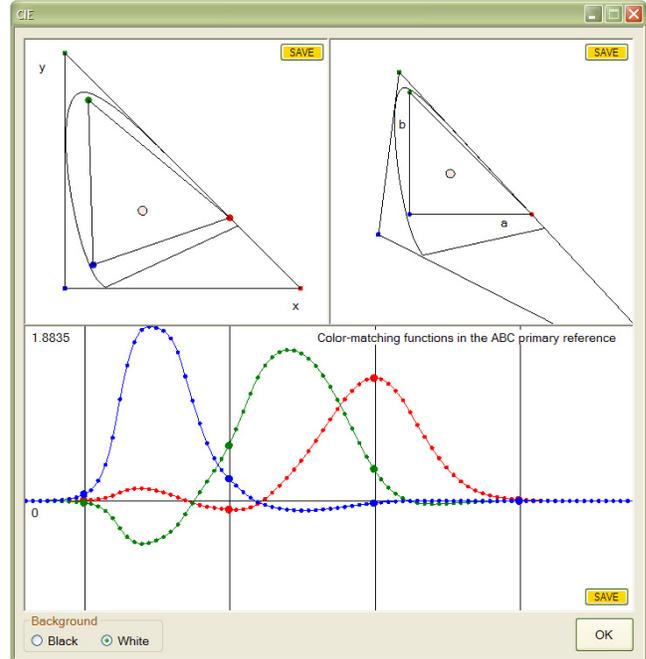


Figure 4. Tristimulus space transformation. Chromaticity diagrams and color-matching functions are shown.

Delta E

This toolbox calculates the color difference between 2 samples using CIE 76, CIE 94, CMC and CIEDE2000 formula. The user chooses:

- the observer
- the illuminant
- the spectral reflectance factor, written in a proper format in an ASCII file.

Graphical comparison of the spectra and visualization of the color difference values is given.

Colour rendering index

The color rendering quality of a light source is represented conventionally by the color-rendering index. This quantity is obtained by comparing the considered light source to a corresponding source with equal correlated color temperature T_c , that is conventionally chosen to be the Planckian source for T_c lower than 5000K, and a daylight type source for T_c equal or greater than 5000K. The result of this comparison is summarized by the color-rendering index, whose maximum value is 100. This value is the color-rendering index of the reference source.

The spectral power distribution of the considered sources must be recorded on ASCII file named with extension .TXT, and written as seen previously.

It is possible to see the spectral reflectance of 14 Munsell samples, the obtained color with the chosen illuminant and the color rendering index with/without adaptation.

Reference illuminant spectra

Blackbody and daylight spectra

This toolbox allows to graphic and save with 1 nm wavelength step an illuminant given as input a temperature in kelvin.



Figure 5. Blackbody and daylight spectra. Graphics given a color temperature of 4000 kelvin.

Colour synthesis

RGB monitor additive synthesis

This toolbox allows to specify a color by RGB system deciding the component of red, green and blue of the monitor actually configured.

Screen plate printing

This toolbox shows on monitor the colors obtainable according to Neugebauer equations by using the CEI standard inks under the illuminant D_{65} and the ideal inks under all the CIE illuminants (standard and recommended). Color samples are shown in tables of 11 columns and 11 rows according to a system of Cartesian coordinates. The percentage areas covered by two inks are in abscissa and in ordinate, respectively, with step 10%. The covering percentage of the third ink is equal for all the samples and can be chosen with step 1%. The not shown color samples cannot be represented by the monitor used. The standard observer is CIE 1931. The observer chooses:

- two inks, whose percentage covering areas are in abscissa and ordinate
- the kind of inks, ideal or standard CEI
- the illuminant, in the case of ideal inks
- the percentage covering area of the third ink
- the way to propose contiguous colors, with or without separating line (in this way, simultaneous contrast disappears and appears).

Two pigment mixture

Color subtractive mixing is given for color layers with spectral reflectance factor obtained by two-flux Kubelka-Munk model. Only the contribution internal to the layer is considered. The aim of this toolbox is to show the dependence of the color on the mixing ratio of only two pigments. For this aim, the surface phenomenon considered by the Saunderson correction can be ignored.

The observer has to choose a pigment pair from a set 28 (the colors shown in the choice windows are obtained by mixtures at 50% with the white pigment).

The exercise is under the illuminant D65 and for the CIE 1931 observer. Additional choices add no other value to this exercise.

Eleven color samples are obtained by mixing two pigments in variable ratios with 10% steps. The colors non reproducible by monitor are simulated and marked.

The spectral reflectance factors, the quantity $[\log(S(\lambda)/K(\lambda))]$ and the chromaticity (x, y) are plotted.

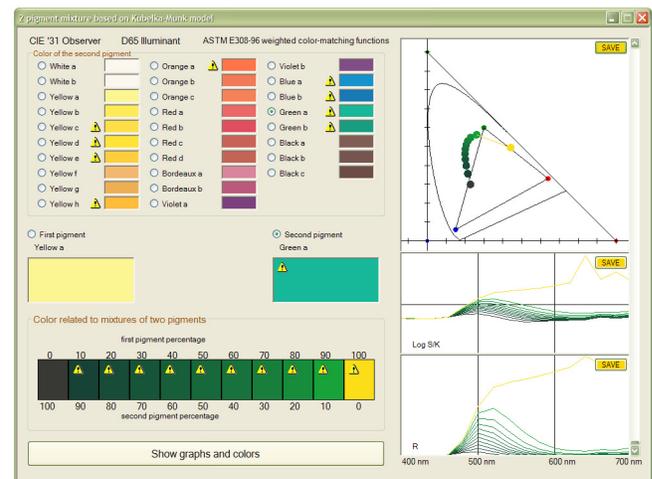


Figure 6. 2 Pigment mixture. Mixture with "Yellow a" and "Green a" pigments is shown. An exclamation mark at any concentration c means that this mixture is not reproducible with monitor in use. On the right side CIE '31 chromaticity diagram, spectral reflectance factors and log of the ratio S/K are shown.

Four pigment mixture

Color subtractive mixing is given for color layers with spectral reflectance factor obtained by two-flux Kubelka-Munk model and Saunderson correction. The observer chooses 4 pigments (the colors shown in the choice windows are obtained by mixtures at 50% with the white pigment). The color related to the chosen four pigments are shown on a three-component diagram in correspondence to any fixed concentration of the fourth pigment. The color reproduction depends on:

- the standard observer
- the illuminant
- the refraction index of the vehicle containing the pigment grains

- the measurement geometry of the spectral reflectance factor (that is supposed measured with integration sphere and may with specular component included or excluded).

The observer can verify visually the effect of variation on measurement geometry, of the illuminant and of the refraction index of the vehicle.

Tools

Spectral data view and download

This toolbox shows graphics relative to:

- Illuminants
- Color-matching-functions
- Illuminant-observer weights
- Sources saved on file

For the first 2 points is possible to save spectral data on file with 10 nm wavelength step, for the 3rd with 10 and 20 nm wavelength step.

Saved file opening

This toolbox allows the user to open “.cvc” files (own software format) relative to color data o color differences.

Database look-up

This toolbox allows the user to open database and browse all data used by the software.

References

- [1] A cura di C. Oleari: *Misurare il colore*, Hoepli, Milano, 2a edizione, 2008 (first edition 1998).
- [2] S. M. Newhall, D. Nickerson, D. B. Judd, Final report of the OSA subcommittee on spacing of the Munsell colors, *J. Opt. Soc. Am.*, **33**, 385 (1943).
- [3] Gescheider G. A., *Psychophysics-The Fundamentals*, 3rd edition, Lawrence Erlbaum Associates, Pub, London UK, (1997)
- [4] Kaiser, P. K. & Boynton, R. M., *Human Color Vision*, Optical Society of America, Washington (1996).

- [5] Gegenfurtner K. R., T. S. Lindsay Eds, *Color Vision, From Genes To Perception*, Cambridge University Press, Cambridge UK (1999).
- [6] Valberg A. *Light Vision Color*, Wiley, Chichester UK (2005)
- [7] Committee on Colorimetry of the O.S.A., *The Science of Color*, OSA - The Optical Society of America, Washington (1963).
- [8] Shevell S., *The Science of Color*, 2nd ed, OSA-Elsevir, Amsterdam (2003).
- [9] Le Grand Y., *Light, Colour and Vision*, Second Ed., Chapman and Hall, London (1968).
- [10] Wyszecky, G. & Judd, D. B., *Color in Business, Science and Industry*, John Wiley & Sons, New York (1975).
- [11] Wyszecky, G. & Stiles, W.S., *Color Science*, John Wiley & Sons, New York (1982).
- [12] MacAdam, D. L., *Color Measurement*, Springer-Verlag, Berlin (1985).
- [13] MacAdam, D. L. Ed., *Colorimetry-Fundamentals*, SPIE MS 77, SPIE - The International Society for Optical Engineering, Washington DC (1993).
- [14] Hunt, R. W. G., *Measuring Colour*, Third Edition, Fountain Press, Tolworth (1998).
- [15] Billmeyer Jr., F, Saltzman, M., *Principles of Color Technology*, 2nd Ed., John Wiley & Sons, New York (1981).
- [16] McDonald, R. Ed., *Colour Physics for Industry*, Society of Dyers and Colourist, Bradford (1987).
- [17] Sève R., *Physique de la couleur*, Masson- Paris (1996)
- [18] Kuehni R. G., *Color, An Introduction to Practice and Principles*, Wiley, New York USA (1997)
- [19] Kuehni R. G., *Color Space, and Its Division*, Wiley, New York USA (2003)
- [20] Ohta N., Robertson A. R., *Colorimetry – Fundamentals and Applications*. John Wiley & Sons, New York (2005).
- [21] Schanda J., *Colorimetry: understanding the CIE system*, John Wiley & Sons, New York (2007).
- [22] CIE Publication No. 15:2004, *Colorimetry, 3rd Edition*. Commission Internationale de l'Éclairage (CIE).

Author Biography

Gabriele Simone received his Bachelor in Information Technology in 2005, and his Master in Information Science and Technology in 2007 both at University of Milan - Department of Information Technology, Italy.

Actually he's a PhD student at Gjøvik University College, Norway. Since 2004 he has been working and researching in the field of digital imaging and color science. His main research topic is contrast measure and tone mapping algorithms in HDR image.