COLORI
DMT

Color Images
Difference Measurement Tool

User Manual

Version 1.0

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Contents

1 License

COLORI-DMT is a tool for evaluating pointwise color differences in color images. The software is distributed under the license GNU GPLv3 or any later version.

2 System requirements

COLORI-DMT is written in MATLAB® R2022a (The MathWorks, Inc., Natick, MA, USA). The standalone version requires MATLAB Runtime.Please refer to: `https://mathworks.com/help/compiler/install-the-matlab-runtime.html`
The source code requires the full software environment and additional toolboxes: Image Processing Toolbox.
The software has been tested and runs on Windows 10 or higher, Linux Debian x86 64bit, MacOS 12 (Ventura) or higher, both Intel/ARM.

3 Installation

To install the standalone version:

- Download the installer from `https://filippopiccinini.altervista.org/joomla/men-tools` or from the github repository
- Run the installer
- A folder named "COLORI-DMT" will be created in the Application Folder of the OS. The launcher for COLORI-DMT will be found in the subfolder "application"

To run the software from source:

- Download the archive containing the source files from `https://filippopiccinini.altervista.org/joomla/men-tools` or from the github repository

- Extract the files into a folder whose name does not contain any whitespace
- Open MATLAB® and set its path to the previously created folder
- Type "startGUI" in the MATLAB® Command Window to start the COLORI-DMT

4 Workflow of COLORI-DMT

The UI of COLORI-DMT consists of one window that contains all the functions. Functions are organized in *panels* that in turn contain all the commands, displays and options pertaining each function. The UI structure matches the workflow of COLORI-DMT and allows to:

1. Select the **reference image**. This is the image that has to be considered as ground truth
2. Select the **test image**. This is the image that has to be tested against the reference image. Notice that COLORI-DMT will check the match between dimensions of test and reference image
3. Select the **color difference metric**. This is the formula that COLORI-DMT will use to calculate the pointwise difference in color between the two images.
4. Compute the difference in the **Output** panel. The output will be visible as an image in this panel. The calculation will be allowed only if the reference and test images are selected, have matching dimensions and if a metric has been selected.

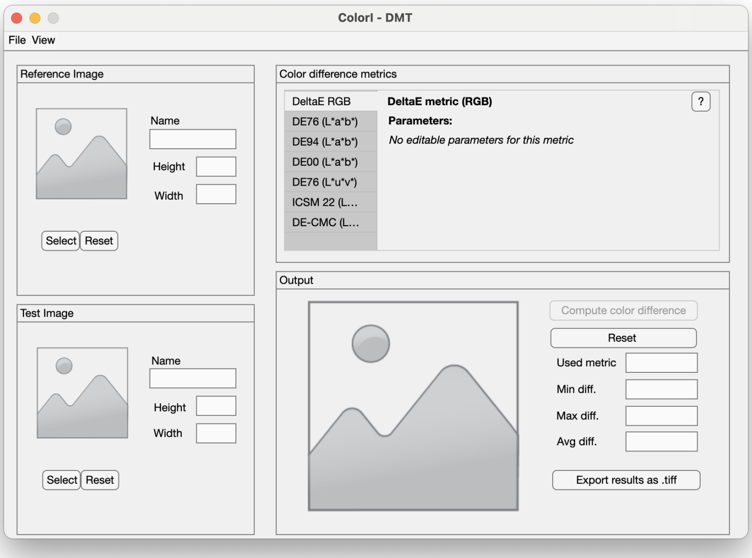
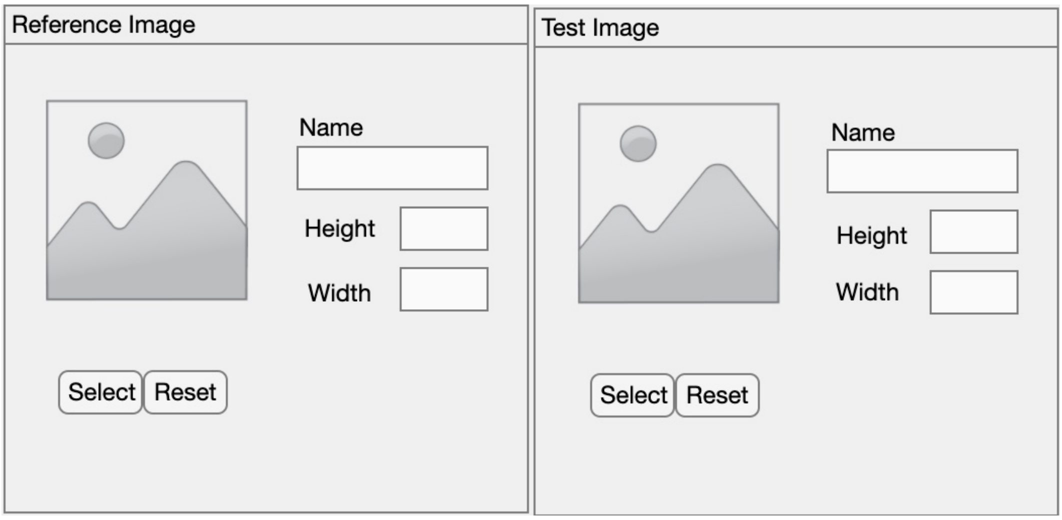


Figure 1: The main window of COLORI-DMT

5 Components of the UI

5.1 Input panels

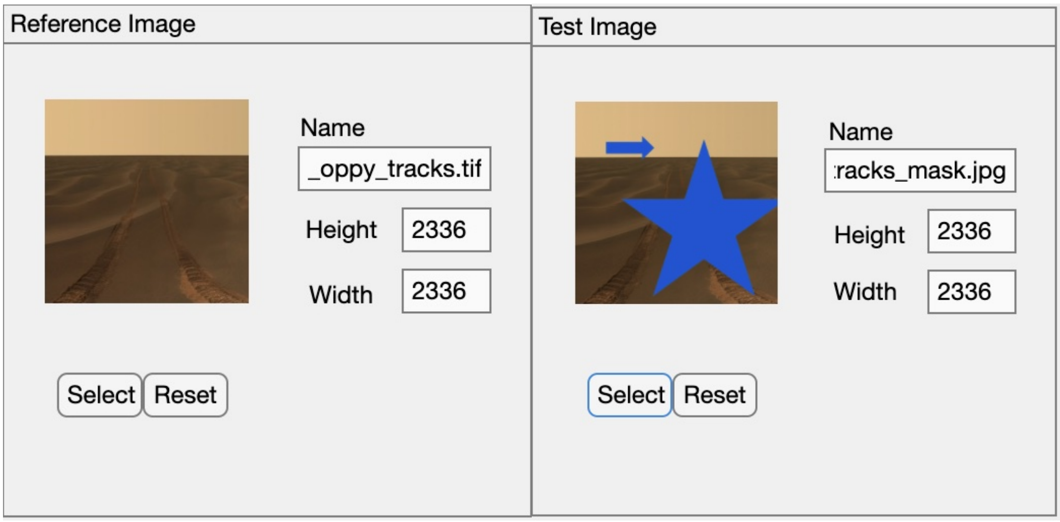


(a) (b)

Figure 2: The reference image and test image panels

The reference and test panels constitute the input panels. Both the panels function in the same exact way. The *select* buttons pop up the image selection dialog box from which is possible to select respectively the reference and the test images. Accepted formats are **.png**, **.tif**, **.tiff**, **.jpg**. The loaded images are converted to 8 bit for the calculation.
Once the images have been selected, their name, height and width will be displayed respectively in the *Name*, *Height* and *Width* fields.
To reset the selection of an image push the *reset* button.[1]

[1]Resetting even one of either images will disable the *compute color difference* button in the *Output* panel



(a) (b)

Figure 3: The selected reference image and test images

5.2 Color metric selection panel

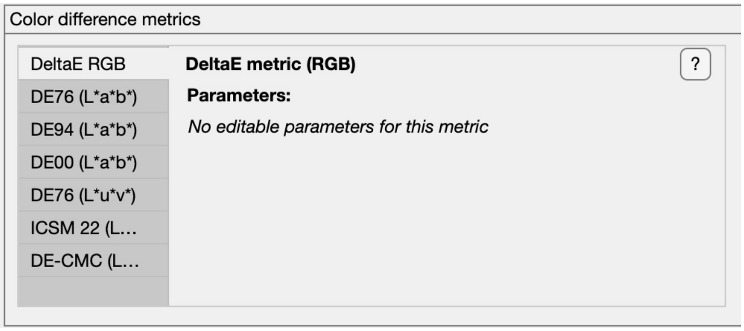
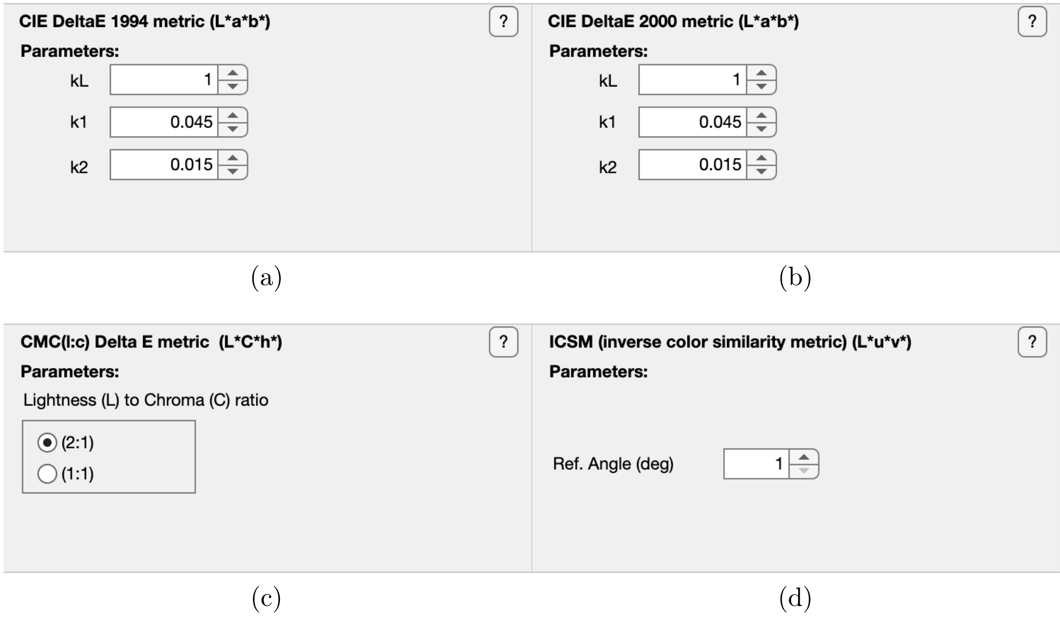


Figure 4: The color difference metrics panel

The *Color difference metrics* panel consists of seven tabs, one for each color difference metric that is implemented in COLORI-DMT. Each panel contains an help button that leads to this manual. For the metrics that so provide, the corresponding panel contain edit fields for editable parameters of the metrics. The *DeltaE RGB*, *DE76($L^*a^*b^*$)*, *DE76($L^*u^*v^*$)* panels do not contain editable parameters. The *DE94($L^*a^*b^*$)*, *DE00($L^*a^*b^*$)*, *DE-CMC($L^*a^*b^*$)* and *ICSM($L^*u^*v^*$)* contain editable parameters as depicted in figure 10.
Details about the meaning and limits of each parameters are discussed in chapter 7 of this manual



(a) (b) (c) (d)

Figure 5: Tabs with editable parameters

5.3 Output panel

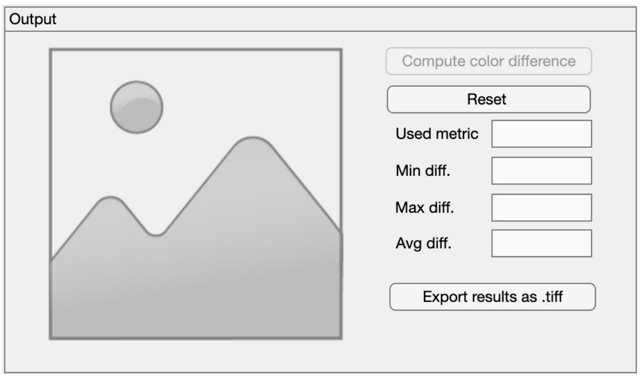


Figure 6: The output panel

The *Output* panel contains the *compute color difference* button. This button stays disabled until the following conditions are met:

- The reference image is selected
- The test image is selected
- One metric among those contained in the *Color Difference Metrics* panel is selected

Upon the meeting of those conditions the buttons becomes enabled and can be pushed to trigger the calculation of the point-wise color difference between the two images. If the images sizes do not match the dialog box in figure 8 will pop up and the calculation wont be executed. Select images with matching dimensions try again.

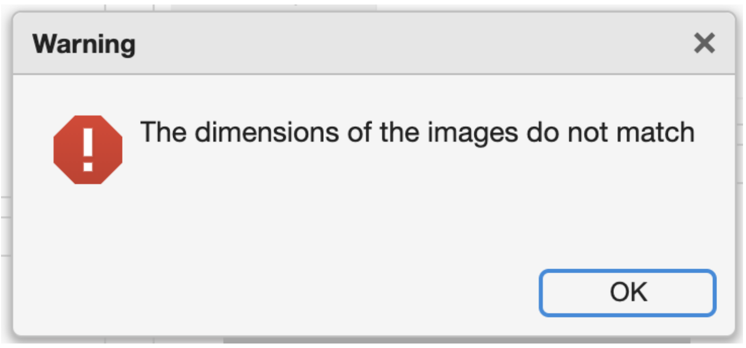


Figure 7: The dialog box that pops up if the dimension of the images do not match

As soon as the calculation is complete, the result image will appear in this panel. The output image is a greyscale image whose pixel values are the calculated color difference, in 8-bit, between corresponding pixels of the reference and test images.

Figure 8: The output panel after the calculation is complete

In the *Used metric* field the name of the metric used for the calculation will be displayed, as well as will be displayed the computed minimum, maximum and average difference value in the respective fields. It is possible to export the result of the difference calculation through the *export results as .tiff* button. A dialogue box will pop up and it will be possible export the results in **.tiff**

format.
Lastly, the *Reset* button will reset the calculation results, as well as the metric selection. If pushed, the panel will revert its state to what it is depicted in figure 6.

5.4 Top menu bar

In the *file* menu of the top bar it is contained the *exit* button. When pushed a dialog box will pop up to confirm the intention of closing COLORI-DMT.[2]

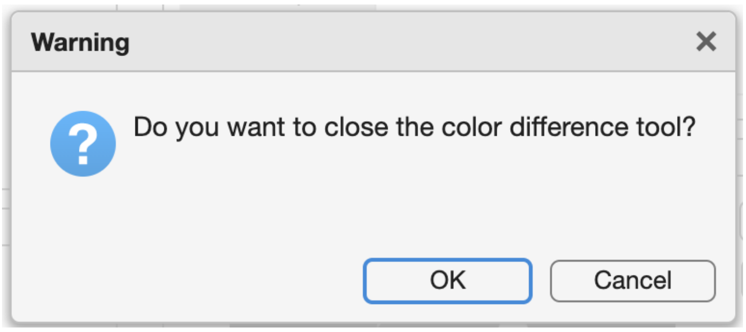
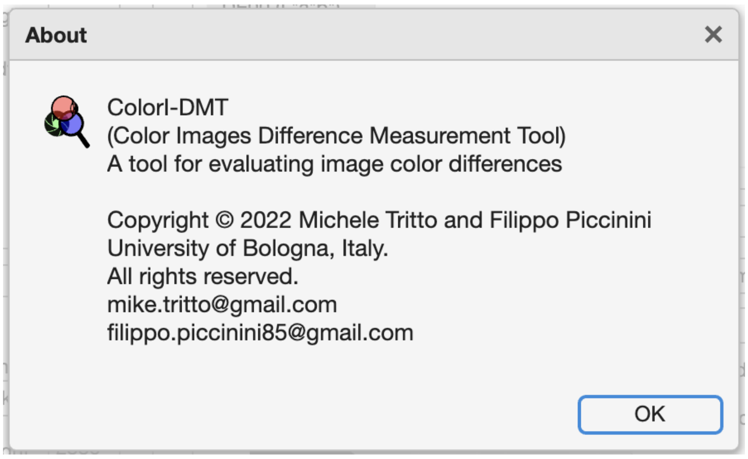


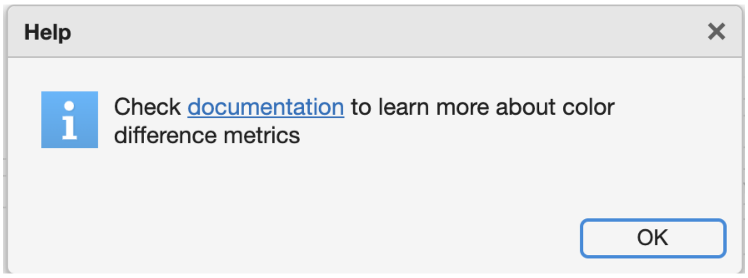
Figure 9: Close dialog box

The *view* item in the top bar menu contains the *about* and *help* buttons. When the former is pushed, a dialogue box will show up containing the information about COLORI-DMT, the copyright declaration and the mail addresses of the Authors. When the *help* button is clicked, this manual will pop open in the default .pdf viewer of the OS in use.

[2]The same dialog box will pop up if the **"X"** button of the UI is pushed.



(a)



(b)

Figure 10: The *about* and *help* dialog boxes

6 Color spaces: CIEXYZ, chromaticity diagram

Color is a perceptual property of the vision process. It is influenced by the anatomy of the eye, its physiology and external factors like the size of the light stimulus that the eye perceives, its intensity, the nature of the imaged object. CIE (Commission Internationale de l'eclairage) standardized **colorimetry** using a set of rules that define the light, the vision apparatus and the imaged object that defined the *standard colorimetric observers observers* (CIE1931 standard colorimetric observer, CIE1964 standard colorimetric observer)[3][1][4].

Color representation and measure lays its ground in the tristimulus values, that is a set of three imaginary **primary colors** whose linear combination allows to reproduce any perceivable color. Tristimulus values also reflects the anatomy of the eye that contains three different types of cone cells sensible each to a different range of the visible spectrum.

$$[C] = a[X] + b[Y] + c[Z] \tag{1}$$

with a,b,c coefficients. **CIEXYZ** is the color space defined in 1931 based upon tristimulus values X,Y and Z and the CIE1931 standard observer [1], for which Y carries also information about the lightness of the color. The CIEXYZ color space contains every color that a human with average eyesight. The X, Y, Z tristimulus values can be refactored as follows:

$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$
$$z = \frac{Z}{X+Y+Z}$$

with $x + y + z = 1$.
The coordinates x and y are known as chromaticity coordinates and measure the relative proportions of the three X,Y,Z primaries. The chromaticity coordinates describe a plane known as the **chromaticity diagram** (CIE 1931 xy chromaticity diagram). Any real color is represented as a pair(x, y) in this plane and the region containing all the real colors is contained within the segment that joins the monochromatic radiation coordinates of $380nm$ and $700nm$, and the spectrum locus curve, that is the curve of chromaticity points described by all the visible monochromatic radiation points. By specification of one absolute component among X,Y ,Z , typically Y as it carries the information about luminance, it is possible to determine in absolute term any color.

6.1 RGB spaces

This family of color space uses as chromaticity values x, y, Y that match the primaries red, blue green. For example, sRGB according to IEC 61966-2-1:1999. RGB spaces gamut cannot reproduce the all the colours perceivable by the human eye. Moreover, they are device-dependent so the representation of colors varies between devices.

6.2 Uniform color spaces: CIE $L^*a^*b^*$ and CIE $L^*u^*v^*$

The CIEXYZ color space and all the color spaces that are defined as subsets of the chromaticity diagram (e.g RGB spaces) suffer the major pitfall that pairs of chromaticity coordinates distant the same amount from one another do not match the same perceptual difference in color. Moreover, x and y alone carry information only about the relative chromaticity of the color but none about the lightess of it, that plays a substantial role in the perception of color.
With the color spaces **CIELAB** and **CIELUV**, CIE formulated non linear

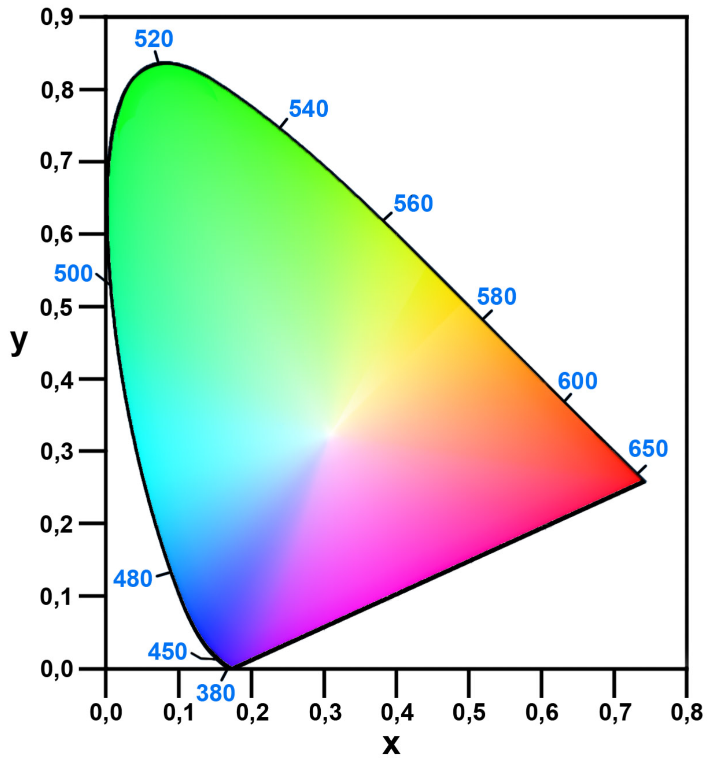


Figure 11: xy chromaticity diagram

transformations that transform the CIEXYZ color space into *uniform color spaces*, uniform meaning that the perceptual difference between colors correlate with the distance color point pairs that have the same distance in the color space. Moreover, both the spaces use as a coordinate *lightness*. [7] [5]
The CIELUV color space has rectangular coordinates L^*, u^* and v^*. The coordinates u^* and v^* are obtained through transformation of the X, Y and Z coordinates of CIEXYZ first to the *CIE uniform chromaticity space*, then u^* and v^* coordinates. The L^* is directly obtained from CIEXYZ and is the coordinate of lightness.
The CIELAB too is derived from CIEXYZ; it has rectangular coordinates L^*, a^* and b^* derived directly from CIEXYZ [7][6]. The L^* coordinate is the same as in CIELUV, while a^* represents the amount of red or green and b^* the amount of yellow or blue, in dependence to their positive or negative sign.

6.2.1 $L^*C^*h^*$

CIELUV and CIELAB allow for the definition of the cylindrical coordinates L^* (lightness), C^* (chroma) and h^*(hue), commonly used parameters for the perceptual description of colors. The L^* coordinate remains unchanged, while chroma is defined as $C^*_{ab} = \sqrt{a^{*2} + b^{*2}}$ or $C^*_{uv} = \sqrt{u^{*2} + v^{*2}}$ an d $h^*_{ab} = \arctan \frac{b^*}{a^*}$ or $h^*_{uv} = \arctan \frac{v^*}{u^*}$.
COLORI-DMT includes one metric (see 7.2) that works into the $L^*C^*h^*(L^*a^*b*)$ domain.

7 Color difference metrics

COLORI-DMT uses **color difference metrics** to numerically assess the similarity in color between two input images. The color difference formulae measure the distance between the coordinate values of each pixel of the target image and the corresponding pixel in the reference image.

7.1 CIEDE 1976 $(L^*a^*b^*)$

The CIEDE 1976 $(L^*a^*b^*)$ (CIEDE76) color difference is the euclidean distance between two color coordinates, defined as follows:

$$\Delta E = \sqrt{\Delta L^2 + \Delta A^{*2} + \Delta B^{*2}} \tag{2}$$

where

$$\begin{aligned} \Delta L &= L_2 - L_1 \\ \Delta A^* &= A^*_2 - A^*_1 \\ \Delta B^* &= B^*_2 - B^*_1 \end{aligned} \tag{3}$$

7.2 CIE deltaE CMC(l:c) $(L^*a^*b^*)$

The delta E CMC l:c) formula is a weighted euclidean metric that uses nonlinear weighting parameters.

$$\Delta E_{CMC} = \sqrt{\frac{\Delta L^*}{lS_L} + \frac{\Delta C^*_{ab}}{cS_C} + \frac{\Delta H^*_{ab}}{S_H}} \tag{4}$$

The ratio of l and c tells how prevalent the *lightness* has to be over *chroma* in the specific application. In COLORI-DMT the ratio is settable at 2:1 or 1:1, the most commonly used ratio for this metric.

7.3 CIEDE94 ($L^*a^*b^*$)

The color difference formula according to the CIEDE94 formulation is:

$$\Delta E = \sqrt{\frac{\Delta L^2}{k_L S_L} + \frac{\Delta C^{*2}}{k_C S_C} + \frac{\Delta H^{*2}_{ab}}{k_H S_H}} \tag{5}$$

where

$$\begin{aligned}
&\Delta L = L_2 - L_1\\
&\Delta C^*_{ab} = C^*_2 - C^*_1 = \sqrt{a^{*2}_2 + b^{*2}_2} - \sqrt{a^{*2}_1 + b^{*2}_1}\\
&\Delta H^*_{ab} = \sqrt{\Delta a^{*2} + \Delta b^{*2} - \Delta C^2_{ab}} = \sqrt{(a^*_1 - a^*_2)^2 + (b^*_1 - b^*_2)^2 - (C^*_2 - C^*_1)^2}\\
&S_C = 1 + k_1 C^*_1\\
&S_H = 1 + k_2 C^*_1
\end{aligned} \tag{6}$$

The CIEDE94 formula was an attempt to improve upon the results of CIEDE76. It is a weighted euclidean metric. k_L, k_1 and k_2 are weighting parameters that are dependent on the application. k_L, k_C and k_H are parameters set to unity under the hypothesis of compliance with the standard observer. In COLORI-DMT it is possible to choose such parameters. k_L k_1 and k_2 are real numbers bound between $[0, \infty)$:

- k_L can be chosen in steps of 0.05 and is set to 1 as default.
- k_1 can be chosen in steps of 0.005 and is set to 0.045 as default.
- k_2 can be chosen in steps of 0.005 and is set to 0.015 as default.

COLORI-DMT calculates this color difference using the MATLAB "imcolordiff" function.

7.4 CIEDE 2000 ($L'a'b'$)

The CIEDE2000 is calculated in the color coordinates L' a' b' obtained from L^* a^* b^* with the following transformations:

$$\begin{aligned}
L' &= L^*\\
a' &= a^*(1 + G)\\
b' &= b^*
\end{aligned} \tag{7}$$

with

$$G = 0.5\left(1 - \sqrt{\frac{\bar{C^*_{ab}}^7}{\bar{C^*_{ab}}^7 + 25^7}}\right) \tag{8}$$

The color difference formula is:

$$\Delta E = \sqrt{\frac{\Delta L'^2}{k_L S_L} + \frac{\Delta C'^2}{k_C S_C} + \frac{\Delta H'^2}{k_H S_H} + R_T \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}}$$

(9)

where

$$\begin{aligned}
S_L &= 1 + \frac{0.015(\bar{L}' - 50)^2}{\sqrt{20 + L' - 50)^2}} \\
S_C &= 1 + k_1 \bar{C}' \\
S_H &= 1 + k_2 \bar{C}' \\
R_T &= -2\frac{\bar{C^*_{ab}}^7}{\bar{C^*_{ab}}^7 + 25^7} \sin\left[60^\circ \times \exp - \left[\frac{\bar{H}' - 275^\circ}{25^\circ}\right]\right]
\end{aligned} \tag{10}$$

k_L, k_1 and k_2 are weighting parameters that are dependant on the application. R_T is a hue rotation term introduced to resolve the mismatch between perceptual uniformity and difference value in the hue region around 275°. k_L, k_C and k_H are parameters set to unity under the hypothesis of compliance with the standard observer. In COLORI-DMT it is possible to choose such parameters. k_L k_1 and k_2 are real numbers bound between $[0, \infty)$:

- k_L can be chosen in steps of 0.05 and is set to 1 as default.
- k_1 can be chosen in steps of 0.005 and is set to 0.045 as default.
- k_2 can be chosen in steps of 0.005 and is set to 0.015 as default.

The CIEDE2000 formulation improves upon the 1994 formulation increasing the goodness of the measure for hue values in the blue region, where CIEDE94 performs substantially worse.
CIEDE2000 set the industry standard for color difference measurement and is the most used color difference formula across many fields and industries.

COLORI-DMT calculates this color difference using the MATLAB "imcolordiff" function.

7.5 CIE deltaE 1976 ($L^*u^*v^*$)

$$\Delta E = \sqrt{\Delta L^2 + \Delta u^{*2} + \Delta v^{*2}} \tag{11}$$

where

$$\begin{aligned} \Delta L &= L_2 - L_1 \\ \Delta u^* &= u_2^* - u_1^* \\ \Delta v^* &= v_2^* - v_1^* \end{aligned} \tag{12}$$

7.6 ICSM (Inverse Color Similarity Metric) ($L^*u^*v^*$)

The ICSM (Inverse color similarity metric) is a novel metric introduced by Jaafar et. al [9] for the calculation of the similarity between colors in the CIELUV space that attempts to improve upon the CIEDE76 metric with a formula that results computationally less expensive than the CIEDE94 or CIEDE00.
The color difference formula is

$$ICSM = \frac{\omega_{dis} \Delta E^*_{uv}}{d_{ref}} \tag{13}$$

where ΔE^*_{uv} is the CIEDE76 metric in the $L^*u^*v^*$ color space. The term ω_{dis} is a function of the rotation angle of the euclidean distance to the origin of the color space. It has shape

$$\omega_{dis} = 1 + \frac{\theta}{\theta_{ref}} \tag{14}$$

where θ is the angle of the euclidean distance to the origin and θ_{ref} is a control variable that makes the weighting function more or less sensitive to the θ parameter. The more the value of θ_{ref} diverges from θ, the more the formula is sensitive to hue changes.
In COLORI-DMT the θ_{ref} is a parameter can be chosen by the user between 1° and 365°. in steps of 1. Its default value is 1.
The term d_{ref} has the following shape:

$$d_{ref} = \vec{V} \cdot \langle 77.8695, 30.1200, 30.8599 \rangle + 179.2889 \tag{15}$$

where

$$\vec{V} = \frac{\vec{I_1} - \vec{I_2}}{\Sigma|\vec{I_1} - \vec{I_2}|} \times sgn(L_1^* - L_2^*) \tag{16}$$

and $\vec{I_1}$, $\vec{I_2}$ are the coordinates vectors of the 2 colors in exam.

7.7 RGB DeltaE

COLORI-DMT contains also a RGB color difference metric that is euclidean and is hereby defined:

$$\Delta E = \sqrt{\Delta R^2 + \Delta G^2 + \Delta B^2} \tag{17}$$

where

$$\begin{aligned} \Delta R &= R_2 - R_1 \\ \Delta G &= G_2 - G_1 \\ \Delta B &= B_2 - B_1 \end{aligned} \tag{18}$$

8 Index of Figures

References

[1] ISO 11664-3:2012(E)/CIE S 014-3/E:2012 Joint ISO/CIE Standard: Colorimetry — Part 3: CIE Tristimulus Values (Central Bureau of the CIE, Vienna)

[2] J. Schwiegerling, Field Guide to Visual and Ophthalmic Optics, SPIE Press, Bellingham, WA (2004).

[3] Goodman, T.M.. (2012). International standards for colour. 10.1533/9780857095534.2.177.

[4] Luo, M.R. (2015). CIE Tristimulus Values. In: Luo, R. (eds) Encyclopedia of. Color Science and Technology. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-27851-8_371-1

[5] ISO/CIE 11664-5:2016 Colorimetry — Part 5: CIE 1976 L*u*v* colour space and u', v' uniform chromaticity scale diagram.

[6] ISO/CIE 11664-4:2019 | EN ISO/CIE 11664-4:2019 Colorimetry — Part 4: CIE 1976 L*a*b* colour space

[7] Pointer, M.. (2009). A comparison of the CIE 1976 colour spaces. Color Research & Application. 6. 108 - 118. 10.1002/col.5080060212.

[8] Luo, Ming & Cui, Guihua & Rigg, B.. (2001). The development of the CIE 2000 colour-difference formula: CIEDE2000. Color Research & Application. 26. 340 - 350. 10.1002/col.1049.

[9] Jaafar, Muhammed, Irfan (2022): Colour Similarity Measure at Different Brightness Using CIELUV Colour Space. TechRxiv. Preprint. https://doi.org/10.36227/techrxiv.20367420.v1