Color Calibration of Basler Cameras

Content

This White Paper describes in detail what color is, how it can be described in figures and how cameras can be color-calibrated.

The topic of color is relevant for many applications. One example is post-print inspection. Today, thanks to high technology, post-print inspection is an automated process. Sophisticated inspection systems based on cameras check things like labels and packaging. Often this is combined with high demands for the quality of color reproduction, for example, when food packaging is checked, where the imaged foodstuff has to appear "crisp" and "fresh" in order to increase the incentive to buy. For the inspection systems for color-monitoring an optimized, standardized color representation is important, so that different devices and installations produce the same result when presented with the same color information. For example, in the printing industry the printed image is often checked on a monitor by a human observer. To do this, the color on the monitor has to be as realistic as possible in order to prevent incorrect decisions.

This is only one example of many applications where high color accuracy is essential.

1. What is Color?

When talking about a specific color it often happens that it is described differently by different people. The color perception is created by the brain and the human eye together. For this reason, the subjective perception may vary. By effectively correcting the human sense of sight by means of effective methods, this effect can even be observed for the same person. Physical color sensations are created by electromagnetic waves of wavelengths between 380 and 780 nm. In our eyes, these waves stimulate receptors for three different color sensitivities. Their signals are processed in our brains to form a color sensation.

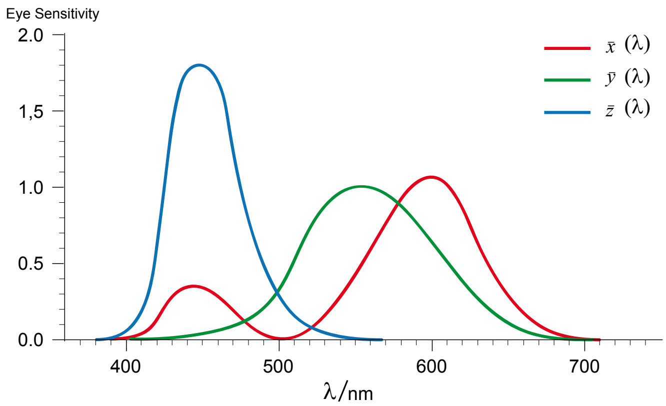

Figure 1: Color sensitivities of the three receptor types in the human eye

But how can colors be described so that they can be handled in technical applications? In the course of time, more than one answer has been found to this question.

In 1931 the International Commission for Illumination (CIE = Commission Internationale de l'Éclairage) defined the Yxy color space, in which all colors visible to the human eye can be described. The commission is an independent organization with the aim of international cooperation for information exchange, for example in illumination matters. Graphically, the Yxy color space is illustrated in the standard color chart for the CIE color system in the shape of a shoe print. In this color chart every color is represented by a point in a plane. The position of the point is described with the variables x, y and Y. x represents the red/purple axis and y the green axis. The Y axis contains information on the brightness of the color shade not included in the standard color chart (the latter is a projection of the entire color space onto a plane).

One disadvantage of the Yxy color space is that it includes colors which cannot be perceived by the human eye. This makes the color space somewhat unwieldy. On the other hand all perceivable colors can be represented in this color space.

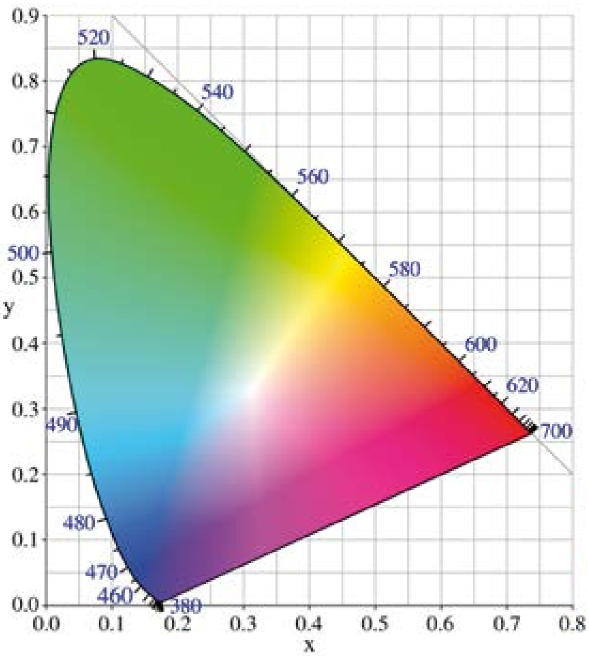

Figure 2: Standard color chart of the CIE color system

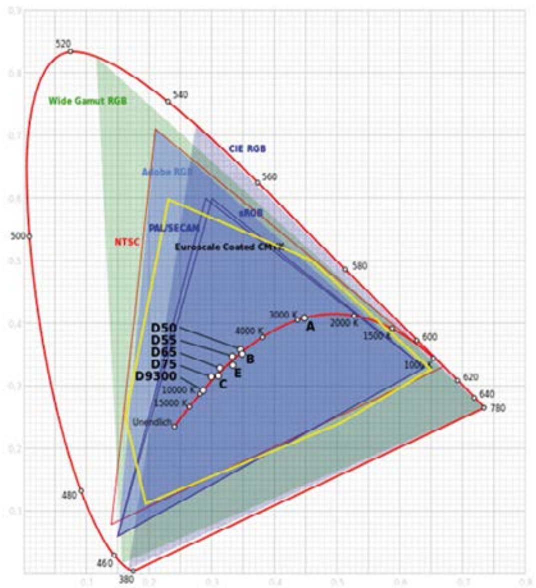

Figure 3: Comparison of different color systems in the standard color chart of the CIE color system

2. Different Color Spaces

For different technical applications typical alternative color descriptions and methods are available, the representation range of which can be illustrated in various partial spaces in the Yxy color space. Examples are the television color methods such as NTSC, PAL or SECAM, the subtractive color model CMYK (cyan, magenta, yellow, key) for color printing applications, the wide gamut RGB and Adobe RGB for professional color reproduction and sRGB (standard RGB) for CRT monitors and the Internet. The described color spaces for all of these methods can be indicated within the Yxy color space as partial spaces and compared with each other.

3. Advantages of the RGB Color Space

In 1996 HP and Microsoft introduced the sRGB (standard RGB) color space. This is the most important standard color space which can be deployed on just about every monitor or printer and in every operating system, browser and every software or internet presentation. It can be realized relatively easily and is widely used, however it is somewhat limited with regard to the colors which can be represented.

If, in contrast, the much larger color space “wide gamut RGB” (e.g. Adobe RGB) is used, the calibration of all of the technical recording and representation equipment is considerably more complex and susceptible to faults.

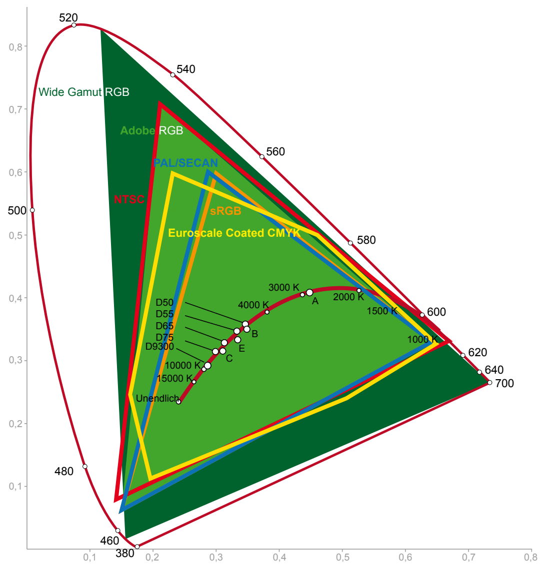

Figure 4: Position and size of the sRGB color space (triangle) within the standart color chart of the CIE color system

4. Advantages of a Calibrated Camera

If a calibrated camera is used, the colors on the sRGB monitor largely correspond to the colors as they appear in reality. With such a calibrated camera you can measure colors and pass on standardized color values. This is particularly important for the printing industry. When using a calibrated camera the colors in the image can be compared to the target values. This is the precondition for achieving a color image true to the original.

5. Different Color Systems

A color system is a specific representation of every color within the color space. Despite the large number of different color systems, some features are common to all of them: In every color system at least three values are needed for characterizing a specific color, e.g. the values R (red), G (green) and B (blue) in the sRGB system, or the values Y (yellow), M (magenta), and C (cyan) in the YMC system. In other systems the color is characterized by two values and the brightness with the third value, e.g. in the YUV (luminance Y and chrominance U and V) in the Yxy system described above or similarly in the HSV (hue, saturation, value) system.

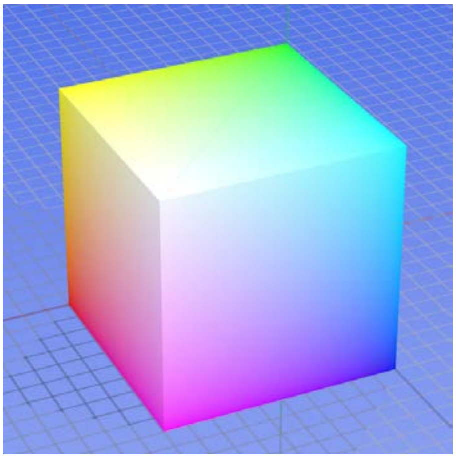

Figure 5: The representation of the RGB color space with R, G, and B axis

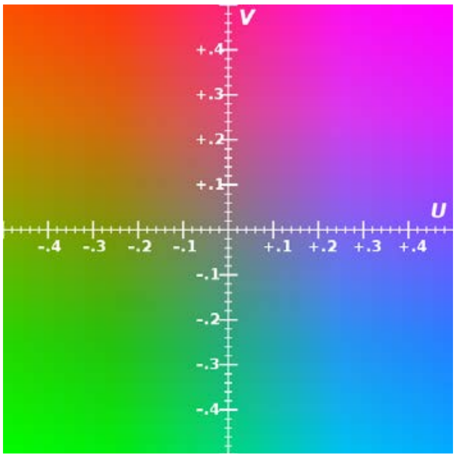

Figure 6: Chrominance component of the YUV system

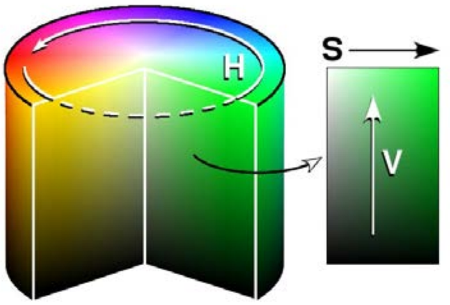

Figure 7: Representation of the HSV system

6. Four Steps of Color Calibration Used by Basler

A color camera uses several pixels with different color filters in order to reproduce the color impression of the real situation for every location in the image by means of three color values. As, without correction, these color values not only depend on the technical detail of the camera but also on the illumination and other factors, some effort is required before one is able to reliably work with the color value determined by the camera. In order to realistically record colors with a camera, color calibration is required.

The powerful color calibration at Basler is a well considered and standardized process consisting of four steps: white balancing, gamma correction, matrix correction and correction by the six-axis operator. These four steps will be explained in more detail below.

The color calibration is carried out by recording as unaltered as possible all of the 24 fields (18 colored and 6 grey fields) on the Greta Macbeth ColorChecker®, a standard tool for the color calibration.

Figure 8: Greta Macbeth ColorChecker®, recorded with the uncalibrated camera (top) and shown with the theoretical target values (bottom)

The target is that the camera records the colors as precisely as the human eye.

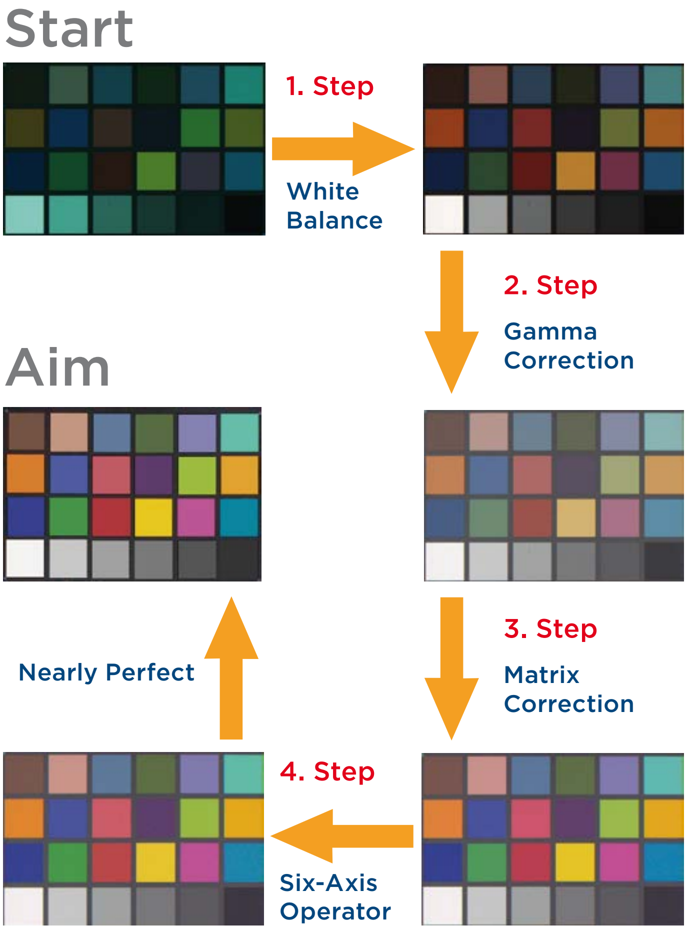

Figure 9: Illustration of the four steps towards a good color calibration: White balancing, gamma correction, matrix correction and correction by the six-axis operator

Step 1 – white balancing

The calibration focuses in the first step - the white balance - on the grey squares in the bottom line of the Greta Macbeth ColorChecker®. The white balancing matches the three color channels to the illumination so that they appear grey, in just the same way as the human eye does this.

Step 2 – gamma correction

After the grey fields, thanks to the white balancing, are now actually grey and no longer show a color tinge, the lightness of the fields is matched to the perception of the human eye. In contrast to a camera sensor, the human eye does not perceive differences in brightness linearly. Instead, the differences in brightness in the dark areas are perceived to be greater while they appear weaker in bright areas. This also influences the color perception very strongly. Without correct gamma correction, color representation is not possible because otherwise the color saturation would depend on the brightness.

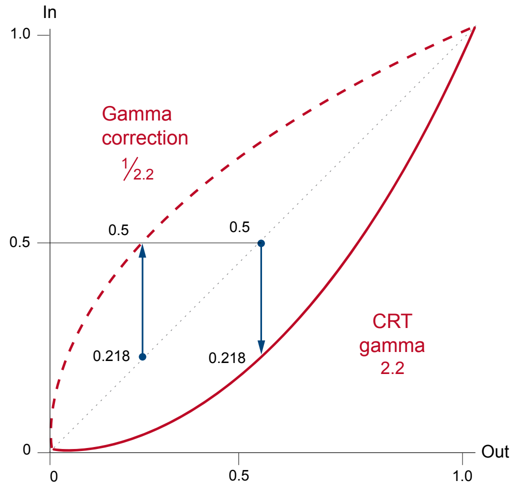

Abbildung 10: Helligkeitswahrnehmung des menschlichen Auges bzw der Kamera (obere Kurve mit Gamma 1 / 2,2) und Gamma-Korrektur der Ausgabegeräte (untere Kurve mit Gamma 2,2)

Step 3 – matrix correction

The name of the correction refers to the calculation for realizing this operation, in which the input values are transformed to the corrected values by means of a so-called matrix multiplication. The matrix correction is an attempt to match the spectral sensitivity of the color pixels in the sensor (color filter of the sensor) to the spectral sensitivity of the receptors in the eye. The correction step works with just six free parameters. For this reason the optimum result is not normally achieved in this operation. The final gap is closed in the next correction step.

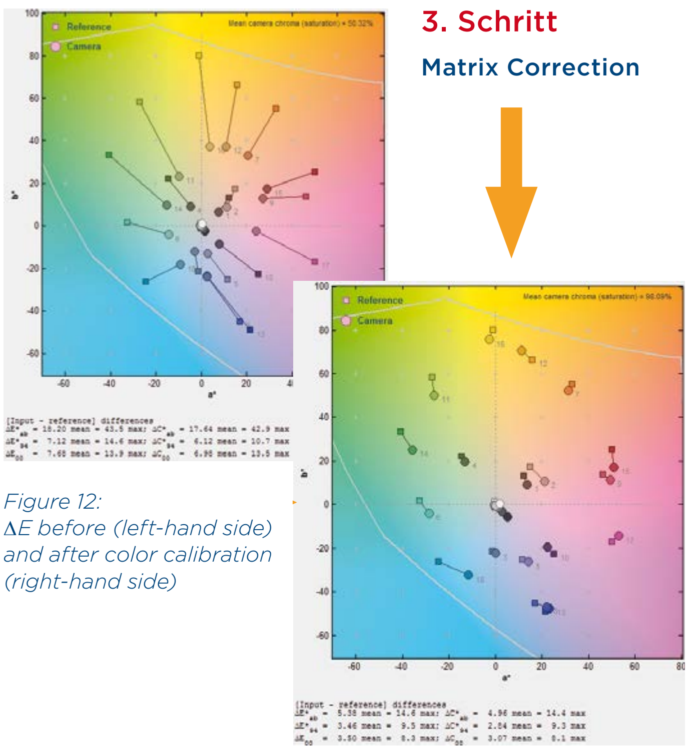

Figure 12: ΔE before (left-hand side) and after color calibration (right-hand side)

Step 4 – correction by means of the six-axis-operator

The six-axis-operator is used for the fine correction of the color representation. In contrast to the matrix correction, its adjustment is intuitive. The user can therefore use this correction step in addition to match the representation to his personal color sensitivities.

For Basler cameras, a color calibration can be carried out in a few steps by means of the pylon software.

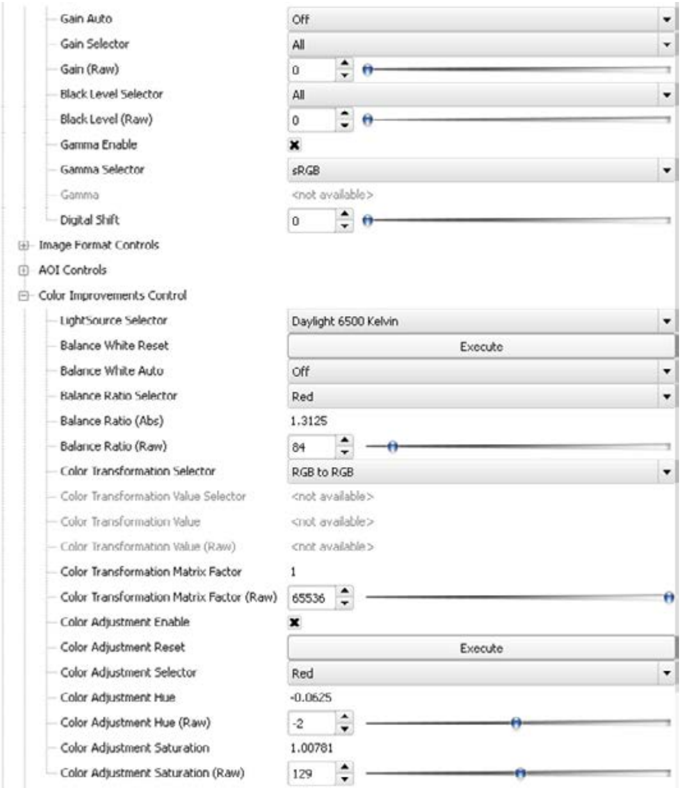

Figure 11: Color calibration of Basler cameras via the pylon GUI

7. Summary

How good the color representation of a camera is can be checked by means of the color fault (ΔE).

ΔE is a measure of the color difference perceived by a person between two colors. A color difference of ΔE < 1 is barely perceivable; a color withΔE > 5 is seen as a different color. Industrial cameras without color correction have a ΔE of 10 to 20.

Thanks to the color calibration Basler cameras achieve an ΔE of 3-4 which corresponds to the high standard of the printing industry.

Basler AG
Germany, Headquarters
Tel. +49 4102 463 500
Fax +49 4102 463 599
sales.europe@baslerweb.com
www.baslerweb.com

USA
Tel. +1 610 280 0171
Fax +1 610 280 7608
sales.usa@baslerweb.com

Asia
Tel. +65 6367 1355
Fax +65 6367 1255
sales.asia@baslerweb.com

BASLER the power of sight