Accurate color measurement

MEASURING ACCURACY OF TRISTIMULUS COLOR SENSORS IN INDUSTRIAL AUTOMATION

Currently, surface color measurements are predominantly carried out using spectrophotometers due to the achievable colorimetric accuracy and the independence from the light source used. By contrast, the chromaticity values of tristimulus color sensors are considered inaccurate and are also intrinsically tied to the light source used.

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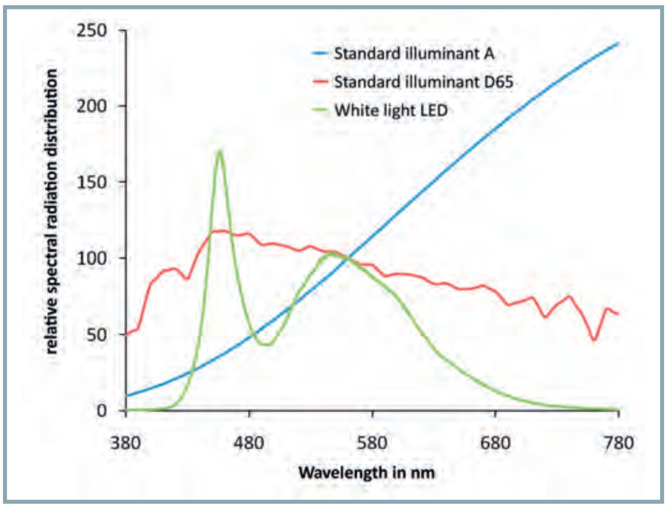
Surface color measurements are an important instrument for objective identification of color appearances and thus make a key contribution to quality assurance in the manufacture of high quality products (for example, painted automotive parts). At present, color measurement is primarily performed using spectrophotometers [1]. The reason for this lies partly in the absolute accuracy that can be achieved. However, spectrophotometers also enable chromaticity values to be output regardless of the spectral characteristics of the light source used.

To specify chromaticity values, spectrophotometers use illuminants standardized by the International Lighting Commission (CIE), such as illuminant A or D65, which are incorporated into the measured result mathematically and therefore provide comparability on an absolute basis [2].

By contrast, the chromaticity values of color sensors used in industry based on



1 Measured spectrum of a white light LED compared to the standard illuminants A and D65

the tristimulus method depend on the spectral properties of the light source used. This is because no spectral resolution information is available, only the integral result. It is not possible to separate the spectrum of the light source and the reflection spectrum of the measured object.

In most cases, modern color sensors use white LEDs as light sources [3]. Figure 1 shows the measured relative spectral radiation distribution of a white light LED compared to the standard illuminants A and D65 commonly used for color measurements.

The radiation function of white light LEDs is not standardized. This is the reason why there is generally no comparability with the chromaticity of spectrophotometers. However, it also means that no conclusions can be drawn about the measurement accuracy that can be achieved by tristimulus color sensors. The measured values are only comparable if using the same illuminant or a light source with identical spectral radiation distribution for both equipment classes.

Color measurement technology

Modern spectrophotometers use a diffraction grating to spectrally disperse the light. Either photodiode arrays or CCD line sensors are used for light detection (Figure 2). All data processing is carried out numerically. Because of the better spectral characteristics, thermal radiators (such as halogen lamps) with a corresponding short service life are often used as light sources. The spectral resolution can be less than 1 nm, while the measurement rate is low, reaching a maximum of a few Hertz. This type of equipment is mainly designed for laboratory use. As high quality optical components are used to ensure the required measuring accuracy, spectrophotometers are comparatively expensive.

Color sensors based on the tristimulus method use three simple PIN photodiodes (preceded by interference filters) as light detectors. The equipment is intended for industrial automation use and therefore has appropriate design features such as a sturdy and ready-to-install aluminum housing, 24 V power supply, PLC interface and an integrated long-lasting light source (Figure 3). In addition, modern color sensors use various compensation mechanisms to minimize the appearance of ambient light, aging and temperature ▶

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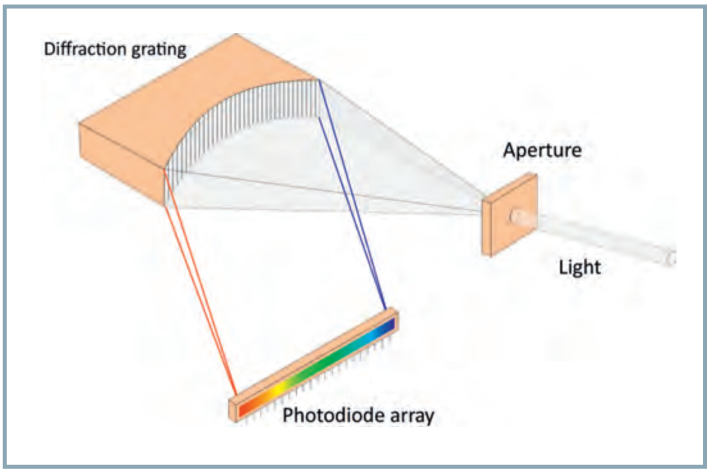

2 **Spectrophotometer principle**

drift, thus guaranteeing continuous operation without the need for intervention or maintenance. The equipment is economical and achieves high measuring rates of more than 10 kHz [4].

Accuracy test

A ›Cromlaview‹ color sensor, type ›CR200‹ with integrated high power white light LED was available for the accuracy test. To obtain the chromaticity values for the accuracy test, a widely used test color chart with 24 color fields (›ColorChecker‹) was chosen as the measurement object. The standardized ›8/d arrangement‹ was used as the measurement geometry, realized using an integrating sphere. This involves illuminating the sample with an 8° angle of incidence. By contrast the reflection is evaluated as a diffuse hemisphere. From the 24 color fields on the test color chart, the reflection spectra were initially recorded in the range between 380 and 780 nm with an increment of 0.32 nm using a spectrophotometer. From these reflection spectra, chromaticity values in the $L^*a^*b^*$ color space were then calculated for standard illuminants A and D65 and when using the color sensor's white light LED spectrum. The 24 color fields were then measured with the color sensor using the same optical accessories and the same measurement geometry.

3 Industrial color sensors based on the tristimulus method

Prior this the color sensor was only white balanced by a ›Spectralon‹ white standard.

Figure 4 shows the results of the measurements in a bar chart. The color variations for each color chart field are shown in ΔE relative to the chromaticity values determined by spectrophotometry when using the white light LED spectrum. The major variations for illuminants A and D65 can be identified. By contrast, the variations for the color sensor without correction are very moderate. The mean value is ΔE = 3.9 with a maximum of ΔE = 9.0. If we apply a simple linear correction method to the measured results, corresponding to equations (1) and (2) [5], the variations fall considerably to a mean value of ΔE = 1.07 and a maximum value of ΔE=2.34.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \underbrace{\begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}}_{\underline{\underline{A}}} \cdot \begin{pmatrix} X_{Ist} \\ Y_{Ist} \\ Z_{Ist} \end{pmatrix}$$

$$\underline{\underline{A}} = \underline{\underline{XYZ_{Soll}}} \cdot \underline{\underline{XYZ_{Ist}^T}} \cdot \left(\underline{\underline{XYZ_{Ist}}} \cdot \underline{\underline{XYZ_{Ist}^T}} \right)^{-1}$$

INFO: Color sensors

Color sensors are frequently used close to the process in automation systems. However, many applications do not require extremely accurate chromaticity values. Typically, a relative color comparison is carried out using saved patterns. Examples of these applications include:

- Coating inspection (for example primer application, grease)
- Color code checking (vehicle fuses, caps on blood sample tubes)
- Color sorting (glass bottle color, colored plastics)
- Presence monitoring (o-ring fittings, sealing caps)
- Position monitoring (upper and lower side of films or seals coated on one side)
- Color and printed marking detection (printed markings on offset printed sheets or color markings on ball bearing shells)
- Transmission measurements (color changes in liquids, filter glasses)
- Primary light sources (testing LEDs for color and brightness)

By contrast, if the color properties of objects are of direct interest, very precise chromaticity values are required in quality assurance. This is particularly true where the color of products represents an identifying feature. Well known examples include the product colors of ›Coca Cola‹, ›Milka‹ and ›Nivea‹. In addition, the automotive sector has very high quality demands when it comes to the accuracy of color measurement – for example in painting of vehicle body components. Similar accuracy requirements exist in powder coating, colored anodization and in art printing.

Summary

If we take into account the fact that, for an average person with normal eyesight the perceptual threshold for color variations is $\Delta E \approx 1$, the color sensor demonstrates an acceptable measuring accuracy. However, it definitely cannot be said to be unequivocally suitable for use as a color measuring device for demanding color measurement tasks. Nevertheless, these devices – under the usage conditions found in industrial automation – can certainly be an economical solution for many color measurement applications. The main problem remains the dependency of the chromaticity values obtained on the non-standardized white light LED. Standardization of the spectrum of white light LEDs – and thus the introduction of a new illuminant – by the International Lighting Commission (CIE) would therefore be a desirable move.

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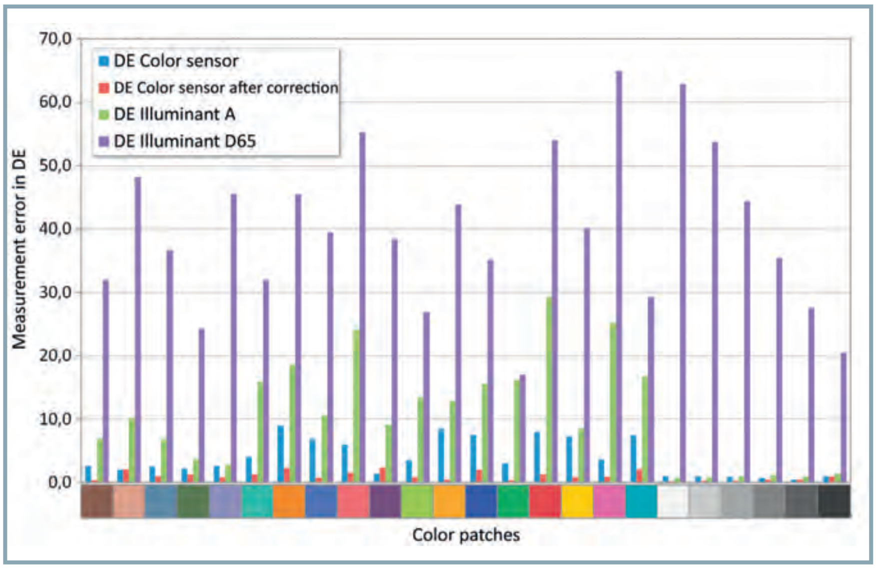

4 Measuring error of color sensor before and after correction, and color variations for illuminants A and D65