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A NATIONAL MEASUREMENT GOOD PRACTICE GUIDE

No. 96

Surface Colour Measurement

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Measurement Good Practice Guide No.96

Surface Colour Measurements

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ABSTRACT

This document is a guide to the measurement of surface colour. It is primarily concerned with visible wavelengths of light in the range 360 nm to 780 nm. Methods of assessing and applying instrumental corrections to the underlying reflectance or radiance factor data are detailed.

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Introduction

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This guide is concerned with the measurement of surface colour. Surface colour measurements are of great importance in the production of a very wide range of manufactured goods. Industry needs to be able to measure colour within the limits of the human eye, about 0.5 ΔE^*_{ab} CIELAB units.

This guide tries to highlight ways of improving operating procedures for surface colour measurements in order to obtain better results from those measurements. It is assumed that surface colour measurements are to be made using an internationally accepted measurement geometry, such as specular included, specular excluded or 0°:45°[1]. Other measurement geometries or configurations are also being used to understand measurements of special effect surfaces such as metallics. They too may be affected by many of the subjects presented in this guide.

Error sources in surface colour measurements were investigated in a research project looking at international colour scales, entitled “Harmonisation of National Scales of Surface Colour Measurements". This project was approved and funded within the EU Fourth Framework Programme under contract SMT4-CT96-2140. From this project correction factors were derived along with measurement methods that minimised the uncertainty in surface colour measurements so that 95 % of the measurements made in different laboratories agreed to within 0.5 ΔE^*_{ab} CIELAB units. The project produced a good practice guide to surface colour measurements. Some of the contents of that guide have been used as a basis for this guide.

All colour measuring instruments need some means of calibration. This guide considers items that should be contained in a spectrophotometer calibration set, measurement error and sources of uncertainty.

The guide is intended to be practical, avoiding equations as much as possible, without looking in detail to the origin of the problems, but giving solution to them.

Colour measurements made using spectrophotometers are calculations derived from the underlying reflectance or radiance factor data over the spectral range 380 nm to 780 nm. The corrections applied to the reflectance or radiance factor data to improve the measurement result can also be derived and applied outside this wavelength range.

Reporting of colorimetric data also needs to be made in a standard way. Colorimetric data are always calculated for a specific illuminant (usually one of the CIE Standard Illuminants A and D65 or CIE Illuminants, for example, C and D50), a specific observer (either the CIE 2° or the CIE 10° Standard Observer), and a specific measurement geometry.

[1] In 2004 CIE changed the manner is which the various recommended geometries are designated. Thus 0°x:45° replaces 0°/45° where the x indicates that the illumination and the viewing angles are in the same plane. If the illuminatuion were annular then the new designation would be 0°a:45°. For further information see CIE:2004 *Colorimetry*[2]

Measurement Instrument Considerations

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IN THIS CHAPTER

- Specification
- Geometric aspects
- Instrument start-up
- Linearity of the measurement system
- Reproducibility and repeatability
- Wavelength scale
- Stray light
- Bandwidth
- Short and long term aging of instrument
- Instrument calibration set

Colour measuring instruments come in a variety of sizes and configurations. They may be large spectrophotometers with bolt-on colour measurement accessories, single or dual geometry bench-top spectrophotometers, hand-held spectrophotometers or colorimeters. Instruments can be either single or double beam, with one or more light sources and/or detectors, have diode-array detectors or separate detectors, scan over an extended range of wavelengths, or have a fixed wavelength range. Many instruments have their own internal calibration routines and/or calibration artefacts. It is advisable however, to obtain other calibration artefacts to independently check the instrument performance or ensure that the samples or artefacts have been traceably calibrated. Spectrophotometers will give spectral data, which are then used to calculate the colour data. Colorimeters will give only the colour data, usually for a restricted range of standard observer and standard illuminant combinations. The availability of this variety of colour measuring instruments means that all or some of the following need to be considered.

2.1 Specification

Ideally, the process of assessing a colour measuring instrument starts before an instrument is purchased. The manufacturer will provide some performance criteria for the instrument. This may include such things as wavelength range, wavelength intervals, wavelength accuracy, type of sources providing the illumination, source stability, warm-up time, measurement repeatability, smallest measurable colour-difference, inter-instrument agreement, operating temperature, cost etc. Most new instruments also have start-up self-test routines and calibration routines to ensure the instrument cannot be used unless it is fully functioning.

The user needs to have a clear idea of what measurements, associated uncertainties, wavelength ranges, etc. they require. This will ensure that the manufacturer's specification for the instrument can be compared to the user's requirements, and appropriate instruments, short-listed for consideration of other criteria.

Over the life of the instrument, there is a need to record the environmental conditions of the instrument, sample compartment, room etc., to identify long term changes that are occurring to the instrument and to identify possible causes of any anomalous effects that may occur.

2.2 Geometric aspects

It is essential to make sure that the instrument's measurement geometry conforms to internationally accepted illumination and observation angles; specular included or excluded, or 0°x:45°, or 45°x:0°. Normal illumination is understood as the beam impinging the surface at any angle between 0º and 10º. The specular included and excluded geometries involve using an integrating sphere to make the measurements. The measurement geometries, angular tolerances, ratio of sphere surface area to area of sphere ports, maximum angle of acceptance, etc are defined by the International Commission on Illumination (CIE) and are given in CIE Publication 15:2004[2].

Consideration also has to be given to where the light dispersing element is placed in the system. This is usually a diffraction grating but could be a prism or a series of filters. Light

dispersion could happen before the sample, resulting in the sample being illuminated with only a small band of wavelengths – monochromatic illumination, or after the sample, in which case the sample is illuminated with the full wavelength range – polychromatic illumination. This has implications for the type of detectors used in the system. Instruments with light dispersion before the sample tend to be scanning instruments that have a single detector output. The detector is sensitive to a range of wavelengths. Instruments with dispersion after the sample usually have multiple detector outputs, e.g. from a diode-array mapped to the wavelength range of the instrument. If wide spectrum illumination is used (incandescence lamp, continuous xenon lamp, xenon flash lamp) be aware of fluorescent samples. The source has to match a CIE standard or recommended illuminant (A, C, D65 etc.) as closely as possible to correctly determine colour coordinates. If this is not accomplished, the surface colour of fluorescent samples has to be measured by the double monochromator method[3]. Fluorescence is present in many objects and even in some white standards. Another thing to bear in mind is that heating and thermochromism effects may give measurement problems when the sample is directly irradiated with the full wavelength range of the source.

2.3 Instrument start up

Perform the start up routine as indicated by the instrument's manufacturer. Currently this is automatically carried out by most spectrophotometers and colorimeters when switched on.

The period of time elapsing for stable results should be determined. Stable results occur when the change in the instrument reading from one value to the next is within acceptable limits. The instrument manufacturer may suggest a warm-up time. Generally, let the instrument warm up for a period of time that has been estimated to give stable displays/results, but never less than the time suggested by instrument's manufacturer, or thirty minutes.

2.4 Linearity of the measurement system

The accuracy of an instrument requires either a linear instrument response or accurate knowledge of the deviations from linearity. A linear instrument response means that, over a specified range, the output signal of the detector is exactly proportional to the input signal. Any non-linearity in the output of the detector system, that is the detector and it's associated electronics, will change the measurement results. Checking the linearity is discussed in more detail in section 4.1.

2.5 Reproducibility and repeatability

Reproducibility data is obtained by measuring a sample, removing the sample, replacing the sample and making another measurement, and then repeating this sequence a number of times. The replacement of the sample in the instrument needs to try and achieve the same alignments and measure the same area of the sample at the same angle as before. The standard deviation of these measurements divided by the square root of the total number of

measurements (the standard error), gives an indication of the reproducibility and can be included in any total measurement uncertainty assessment.

Repeatability data is obtained by measuring a sample, leaving it in place and making another measurement, and then repeating this a number of times. The standard deviation of the measurements divided by the square root of the total number of measurements, then gives an indication of the repeatability and can be included in any total measurement uncertainty assessment. This is a Type A (evaluated by statistical methods) uncertainty[4].

2.6 Wavelength scale

Wavelength scales in colour measuring instruments are difficult to assess unless you are using a scanning spectrophotometer, where a narrow emission line discharge lamp or some other wavelength standard may be used. This is discussed further in section 3.1.4

2.7 Stray light

Stray light is difficult to evaluate. It is light flux reaching the detector outside the spectral distribution prescribed for the measurement or which reaches the detector by a path other than that prescribed. Stray radiant energy is both heterochromatic - of different wavelengths to those set by the spectral bandpass - and isochromatic - of the same wavelengths as those set by the spectral bandpass - but does not travel via the sample. Stray light can be internal or external.

External stray light is that from any source other than the instrument source. It is most likely to be found in instruments which are not adequately enclosed so that light may enter. The obvious way of checking for external stray light is to darken the room or cover suspect areas and note if there is any change in the output signal.

In colour measuring instruments, stray light generally should not be a problem if the instrument designer and manufacturer have done their job properly. Check the manufacturer's specification for any assessment of this they may have done.

2.8 Bandwidth

For an instrument where the spectral bandwidth cannot be set by the user, it is important to know the value used. It is also important to know the form of the slit function. This is the spectral distribution of the light incident on the sample when a single wavelength is selected in the spectrophotometer. It is usually triangular in a scanning spectrophotometer, but not in a non-scanning system, such as those using detector arrays.

Bandwidth is usually not independent of wavelength although it is frequently assumed to be so.

2.9 Short and long term aging of instrument

Once a spectrophotometer has been assessed as passing the required specification and meeting the user's requirements, steps need to be taken to ensure that it continues to meet them during use.

Instruments have to be maintained as indicated in their manual. It is necessary also to pay special attention to the handling and maintenance of the instrument's calibration standards. For those instruments with an integrating sphere, pay attention to the sphere coating. Degradation of this coating produces several errors.

Simple checks should be done every day or every time the instrument is switched on for use. This can be as simple as checking the reflectance at a couple of levels. Then on a longer time scale, e.g. weekly, depending on use and or regulatory requirements, more checks should be made. For example, check the value of reflectance at several levels or wavelength scale at several wavelengths. A full check using all standards should be made periodically as well, e.g. monthly. Using this procedure a history of the instrument's performance can be built up. This may aid in narrowing down the time of occurrence of a problem and in diagnosing the fault. In all cases, if the instrument gives a measurement result outside the value for the standard, then the cause should be investigated, and a service engineer called if the instrument is at fault.

It is useful to also record environmental conditions at the time of measurement as they may influence the measurement result and cause anomalous effects. E.g. temperature of cell, sample compartment temperature, room temperature and humidity.

2.10 Instrument calibration set

Many instruments are supplied with their own calibration set, which contains at least a white standard. A black, or zero reflectance, standard along with other colours may also be included. Often the supplied set may not be comprehensive or have a traceable calibration and therefore it is advisable to buy another more comprehensive calibration set to independently check the instrument performance. This set should ideally contain the following: two white standards (one matt and one glossy), a zero reflectance standard (black trap for reflectance, black glass for 0°/45° radiance factor), a grey standard with about 50% reflectance, a mirror (for reflectance) and a wavelength standard. The function of each of these standards is described in section 3. The standards should be handled carefully to ensure they are not damaged in use. They should also be kept clean as any dirt, fingerprints, etc on them will change the calibration values.

Measurement errors

3

IN THIS CHAPTER

- All Instruments
  - » Incorrect zero level
  - » Absolute scale of diffuse reflectance and 0˚/45˚ radiance factor
  - » Photometric accuracy: Non-linearity of the photo-detector and geometry
  - » Wavelength error
  - » Bandwidth
  - » Thermochromism
  - » Sample inhomogeneities
- Integrating sphere instruments
  - » Differing properties of white reflectance standards
  - » Specular beam exclusion error (gloss trap error)
  - » Specular beam weighting error
- Scanning instruments
  - » Scan speed & time constant

Spectrophotometric errors are discussed in this section on a qualitative basis. All are known to affect the measurement result, although by different degrees for different instruments. It is the user's responsibility to check the instrument or to trust the manufacturer's specification in this sense.

Not all of the errors affect all instruments. Some, such as the gloss trap error and the specular beam weighting error, are specific to integrating sphere instruments. Others, such as scanning speed and integration time, are specific to wavelength scanning instruments.

3.1 All instruments

3.1.1 Incorrect zero level

Detector noise and stray light within the instrument optics will produce a signal for zero reflectance or zero 0°x:45° radiance factor. This value must be accurately determined and then subtracted from all subsequent readings. It is possible that the dark reading changes with wavelength, so if possible spectral data should be obtained for a zero reflectance or radiance factor standard at the sample position. Simply making a spectral scan with the sample port open is not satisfactory. It is better practice to use a black glass wedge trap at the sample port for the zero reflectance spectral scan for integrating sphere instruments, and a black glass plate for 0°x:45° radiance factor instruments. Some commercial gloss traps provided with integrating sphere instruments to exclude the specular component are not satisfactory as zero reflectance devices. This wedge should not reflect any significant part of the incident light. This will occur if the specular beam undergoes three or more specular reflections within the wedge. As a good rule of thumb, a wedge whose end cannot be seen under standard laboratory illumination is usually a good zero reflectance specimen.

3.1.2 Absolute scale of diffuse reflectance and 0°/45° radiance factor

The instrument scale should be calibrated against standards traceable to a national metrology institute. The calibration tiles provided with many instruments may be traceable to different national scales which may have biases with respect to each other. If measurements made on different instruments are to be compared, then these biases need to be removed and instruments ideally calibrated with white standards that are traceable to the same scale. It needs to be noted that standards used to calibrate instruments have an inherent uncertainty derived from their own calibration with respect to any national standards laboratory's reflectance and radiance factor scales. Also, if the standards are not properly maintained and recalibrated at intervals appropriate to their use, the calibration factors will not be correct, leading to erroneous measurements. Differences of 0.5% in absolute value of radiance factor measurement will produce measurable errors in terms of CIELAB units.

3.1.3 Photometric/intensity accuracy: Non-linearity of the photo-detector and geometry

Photometric accuracy is mainly a combination of two factors. One is related to the geometrical characteristics of the beam used in the spectrophotometer and the other is due to the linearity of the instrument's photodetection system. From optics, it is known that reflectance depends on the angles of incidence, numerical aperture, spectral content and polarisation of the incident beam, together with the angles of collection, numerical aperture, spectral content and polarisation of the reflected beam. Most spectrophotometers have beams of low divergence, but not exactly parallel, very close to normal incidence, polarised to some extent and differ from instrument to instrument. Therefore, even when no error would affect

the measurement, the results may differ from instrument to instrument if the beams are not exactly identical. Fortunately, this contribution to photometric accuracy is small in a high quality instrument and the largest contribution is that due to lack of linearity in the detection system.

The response of a spectrophotometer's detector to light is not always linear throughout its entire range. Towards the higher end, saturation of the detector or electronics may occur. Towards the lower end, the noise floor will limit the minimum measurable quantity. Even in the middle range some effects may occur that modify the linear behaviour normally expected. To check for this, a grey tile of approximately 50% reflectance is the minimum needed. A set of several grey tiles with different reflectance values would give more information about the linearity. The presence of the tile may also modify the response of the system. The zero and 100% points can be assumed to be accurate if zero level and scale corrections have been made. Then a formula, based on a polynomial, can usually be fitted for linearity correction across the range tested.

3.1.4 Wavelength error

Wavelength errors will lead to colorimetric errors, so the instrument's wavelength scale should be checked. Several wavelength standards are available including spectral emission line sources, reflectance tiles and transmission filters (e.g. McCrone, Holmium). The user must use the most appropriate for their instrument type.

To calibrate the wavelength scale in a scanning spectrophotometer with a reflection type wavelength standard, an ordinary reflectance measurement should be made within the interval in which wavelengths are certified, setting the instrument with the same bandwidth and a combination of scanning speed and time constant to be used in the measurement. If the instrument allows for transmission measurements, a transmission filter may be placed at some point in the sample beam, with a white standard at the sample port. Then the wavelength can be calibrated using absorption peak filters by measuring their transmittance with the same parameters as for the measurement.

In a non-scanning instrument checking the wavelength is much more difficult. A reflection wavelength standard should be placed at the sample position and a measurement made using the normal procedure. The position of the wavelength peak or feature can be determined from the spectral data and compared to the calibration position.

If the wavelength error is less than the uncertainty of the standard, no correction should be applied. If the wavelength error is less than 0.1 nm, no correction should be applied because the subsequent colorimetric error is negligible. In other cases, reflectance values should be corrected according to the expression:

$$R(\lambda) = R_m(\lambda) + \frac{\partial R_m(\lambda)}{\partial \lambda}\Delta\lambda \quad (1)$$

where $R(\lambda)$ is the correct reflectance value, R_m is the measured reflectance value and $\Delta\lambda$ is the wavelength scale error, the difference between the actual and the displayed wavelength.

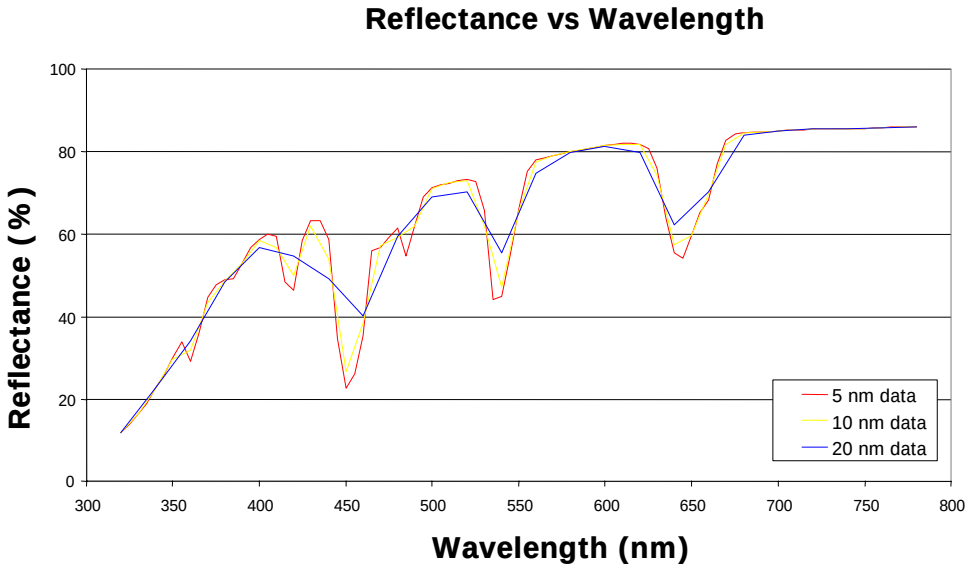
Clearly, this error cannot be checked or corrected in those instruments in which reflectance values are not provided to the user.

3.1.5 Bandwidth

The spectral bandwidth used in recording the reflectance spectrum has an effect on the acquired spectral values. Figure 1 shows two spectra of the same sample obtained with different bandwidths. Clearly this will result in differences between the values of the associated colour coordinates if no action is taken.

From a practical point of view, the error in colour coordinates is negligible if the reflectance spectrum does not change significantly within the spectral ranges compared to the bandwidth value. In most cases a bandwidth up to 5 nm can be used in recording the reflectance or radiance factor spectrum without altering the spectrum. For many instruments this parameter cannot be set by the user, although it should at least be known.

Figure 1: Spectra of the same sample taken with bandwidths of 5 nm, 10 nm and 20 nm



This source of error affects the value of colour coordinates very much like a wavelength error. It is more noticeable in chromatic samples with steep spectral slopes in the reflectance data.

3.1.6 Thermochromism

Thermochromism is change of colour with changing temperature. When specifying the colour of a material the measurement temperature should be specified. Generally the more highly coloured the sample the more thermochromic it is likely to be. This effect is most prominent in materials having spectral distributions with steep slopes, such as those coloured red, orange or yellow. A correction method has been published in the literature for ceramic colour standards[5-8].

In relation to this item, it is advisable to check for temperature difference between the sample placement position and the room temperature. Up to 12 ºC temperature difference has been found in an instrument, but two or three degrees is acceptable.

3.1.7 Sample inhomogeneities

Samples and standards are generally not 100% uniform across their surface[8]. Therefore, the measurement result is an averaged value within the area covered by the incident light. To minimise this error, the reflectance should be measured at least twice by rotating the sample about the optical axis. The final reflectance value should be the mean of the measurements.

3.2 Integrating sphere instruments

3.2.1 Differing properties of white reflectance standards

It has been experimentally shown that when making measurements of matt samples using spectrophotometers which include an integrating sphere accessory, errors may be introduced if the instrument is calibrated using a glossy standard[9]. The same is true for glossy samples calibrated using a matt standard. To avoid this effect it is good practice to measure matt samples against a matt white standard and glossy samples against a glossy white standard.This error should not affect 0°x: 45° radiance factor measurements unless the aperture angle of the instrument varies significantly with respect to that used in the calibration of the standard.

3.2.2 Specular beam exclusion error (gloss trap error)

A gloss trap which does not completely eliminate light specularly reflected from samples can lead to an error when measuring glossy samples in the specular excluded geometry. The amount of error depends on the specific instrument. A method to check for the size of this error consists of measuring the reflectance of a good quality mirror against a matt white standard with the integrating sphere set for specular excluded geometry[10]. A correction coefficient may be calculated from this measurement according to the expression (all reflectances in %):

$$K_2(\lambda) = \frac{4}{M(\lambda)} \frac{\rho_m(\lambda)}{\rho_t(\lambda)} R_t(\lambda)$$

Where ρ_m is the instrument's reading when the mirror is measured, ρ_t is the reading when the white standard is measured, M is the mirror's reflectance, the value 4 stands for the nominal specular reflectance of a glossy sample, and R_t is the white standard's actual reflectance (all reflectances in %). If $K_2 < \pm 0.05$ then the gloss trap is performing well. If larger than this value then the instrument may need realigning. Alternatively, if no linearity correction has been applied to the measurements then a sphere error correction may be applied. This is effective when you have no grey standards and have only used a white standard to calibrate the instrument. The corrected reflectance value would be given by:

$$R(\lambda) = \frac{\rho_s(\lambda)}{\rho_t(\lambda)} R_t(\lambda) + K_2(\lambda)\left(\beta \frac{\rho_s(\lambda)}{\rho_t(\lambda)} - \alpha\right)$$

where ρ_s is the reading when the sample is measured, ρ_t is the reading when the white standard is measured, and α and β are coefficients related to the glossiness of the sample and

the white standard, respectively, and whose values are 1 or 0 for glossy and matt specimens respectively.

Clearly this coefficient cannot be determined in those instruments that do not provide reflectance values, but only colour coordinates. In this case, the measurement could be done and the coordinate representing lightness (Y or L^*) could be examined. If this value is very small, close to zero, then the gloss trap correction error will be negligible. If this value is not close to zero, then the error will be significant but no correction can be applied.

3.2.3 Specular beam weighting error

In many integrating spheres, light specularly reflected may not be evaluated with the same efficiency as light diffusely reflected and an error will be present in the total reflectance measurement of glossy samples. The size of this error depends on the specific instrument.

Like the specular beam exclusion error, a method to check for the size of this error consists of measuring the reflectance of a good quality mirror against a matt white standard with the integrating sphere set for specular included geometry[10]. A correction coefficient may be calculated from this measurement according to the expression (all reflectances in %):

$$K_3(\lambda) = 4\left(\frac{R_t(\lambda)}{M(\lambda)}\frac{\rho_m(\lambda)}{\rho_t(\lambda)} - 1\right)$$

If $K_3 < \pm 0.05$ then the specular beam is being collected with the same efficiency as the diffused light. If larger than this then the measurements may need correcting. If no linearity correction has been applied to the measurements then a sphere error correction may be applied. This is effective when you have no grey standards and have only used a white standard to calibrate your instrument. The corrected reflectance value would be given by:

$$R(\lambda) = \frac{\rho_s(\lambda)}{\rho_t(\lambda)}R_t(\lambda) + K_3(\lambda)\left(\beta\frac{\rho_s(\lambda)}{\rho_t(\lambda)} - \alpha\right)$$

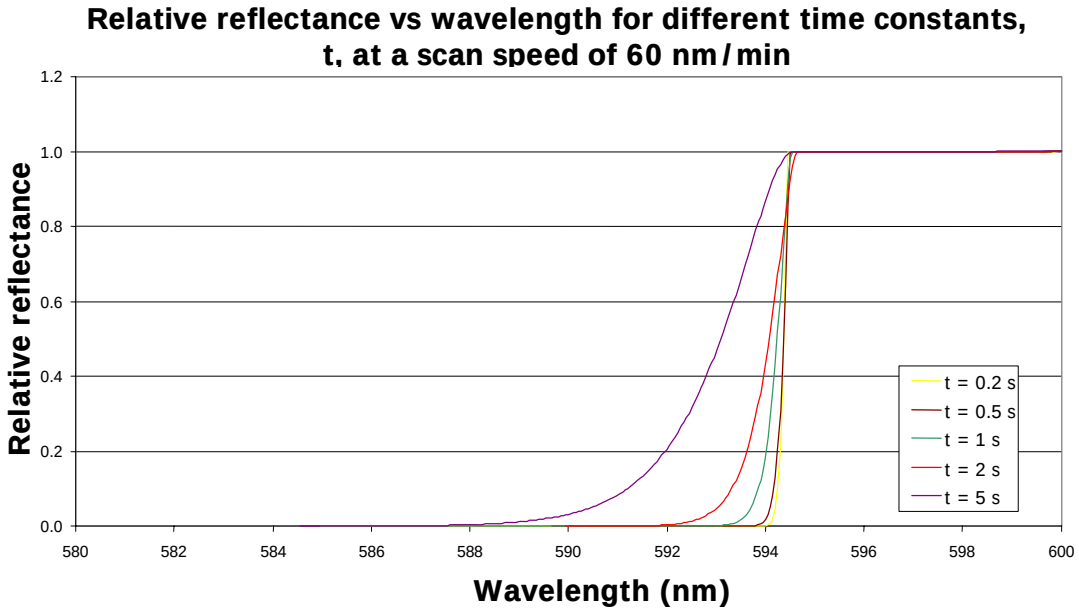
Clearly this coefficient cannot be determined in those instruments that do not provide reflectance values, but only colour coordinates.

3.3 Scanning instruments

3.3.1 Scan speed and time constant

An incorrect setting of the scan speed and time constant leads to an erroneous recording of the reflectance spectrum, as shown in Figure 2, and leads to a subsequent error in calculating the colour coordinates.

Figure 2: Reflectance spectra detail obtained with different time constants



The concept of time constant is used in a scanning spectrophotometer in an ambiguous way, because it relates to the time needed to give a full response to a steep slope change, but different manufacturers associate different limits to the proportion of the final response (68 %, 95%, 99%, etc.). It is necessary to carefully look at the specification of this parameter in the instrument's manual. A good rule of thumb is to use a time constant that reaches 99% of the final response after a steep slope change within the time interval used to sample the reflectance spectrum. If t is the time needed by the instrument to produce 99% of the final response to a steep slope change and d is the sampling spectral interval, the correct scanning speed will be given by d/t.

Which parameter (scan speed or time constant) should have preference? It depends on the specific measurement. Those situations where noise has to be low need the time constant to be set first and then the scanning speed. Those situations where the measurement time has to be minimised, need the speed to be set first and then the time constant.

The effect of this error looks like a wavelength error and it is more evident in the highly chromatic samples and negligible in those that are less chromatic, such as white or grey samples.

Some current scanning spectrophotometers do not allow the user to set the time constant, just the scanning speed. Perhaps the reason is to avoid this problem!

Calculation of Colorimetric Data

4

Calculation of colour coordinates from reflectance values has to be carried out by following the recommendations of international bodies like CIE (Commission International de l'Eclairage)[2]. Tabular data for CIE Standards Observers and Illuminants are given for a 1 nm bandwidth, therefore, from a rigorous point of view, they only could be used with reflectance spectra obtained using that bandwidth and that sampling interval. From a practical point of view however, they can be used, as they often are, for spectra obtained with bandwidths up to 5 nm, using a summation step of the same width. If the measuring instrument uses bandwidths larger than 5 nm to measure the reflectance, then the preferred option is to interpolate the spectral data to 1 nm or 5 nm interval data, correct to 1 nm or 5 nm bandwidth respectively and use the appropriate CIE tables in the calculation of colorimetric data.

For smoothly changing spectral profiles with no discontinuities a practical alternative is to use weighting functions for a given standard illuminant and observer combination, with the assumption of an ideal band-pass function of specified width at half-height. If the source and other features of the instrument are well known, deviations from the ideal band-pass function can be computed. For instance, those functions recommended by ASTM (American Society for Testing and Materials)[11].

Colorimetric calculations are usually carried out within the software of instruments. It is the user's responsibility to verify whether they have been done correctly. The amount of the potential error depends on the sample, but it may be as large as several CIELAB units if a large spectral bandwidth is used or the sample is of very low reflectance.

Instruments which give only colorimetric data, such as colorimeters, contain filters that have spectral sensitivities designed to mimic the colour matching functions. There are limitations on colorimetric accuracy depending on the closeness of match of the filters to the colour matching functions and the need for the light source(s) to closely match the standard illuminant that the data are required for. Colorimetric data are usually calculated by the instrument from the CIE X, Y and Z tristimulus values the filter readings are converted into.

Uncertainties

5

A measurement result will be incomplete if it is not accompanied by its uncertainty value. Currently, there is no universally accepted method for calculating the uncertainties to be associated with colorimetric coordinates, although some methods have been published[10-12]. It is assumed however, that at least the following uncertainty sources should be considered in the estimation of the final uncertainty. Values assigned to each of them, and the method used to compute the combined final uncertainty in colour coordinates, should be specified. It is important to remark that the uncertainty value will not disappear if a correction factor is applied to the measurement, because the correction factor itself will have an associated uncertainty.

Uncertainty sources:

Scale uncertainty (usually via reference standard, e.g. white standard)Photometric linearity uncertainty
Dark level uncertainty
Wavelength uncertainty
Bandwidth uncertainty
Gloss trap or specular beam uncertainty, whichever applies, for integrating sphere geometries.
Repeatability uncertainty

Where spectral reflectance data are available the most common practice used to calculate uncertainties in colour coordinates is to add in quadrature the values assigned to the previous quantities so that a reflectance combined uncertainty value is obtained. This may be a single value or a set of spectral values. Then there are two options. The first is to apply the partial derivative rule to the colorimetric tristimulus equations, to obtain uncertainty values for X, Y and Z and then the partial derivative rule is applied again to the equations defining the colour coordinates of interest in terms of X, Y and Z to obtain the associated uncertainty (x, y, Y), (L^*, a^*, b^*), (L^*, u^*, v^*), etc.[122]

The second uses numerical methods with no need of deriving partial derivatives analytically. The partial derivatives of a colour quantity in terms of each spectral value are obtained by simply calculating the colour coordinates with and without a small change of each input spectral value. The uncertainty of the colour quantity is then obtained as a combined uncertainty for all spectral values[13].

[2] See also NPL Best Practice Guide No. X Uncertainties in surface colour measurements

Cleaning of Surface Colour Standards

6

IN THIS CHAPTER

- Matt ceramic tiles & opal glasses
- Glossy ceramic tiles & opal glasses
- PTFE based standards

Ceramic tiles and other colour standards may over time become dirty and need cleaning. Standards with glossy surfaces are easier to clean than standards with matt surfaces. The best way to avoid having to clean standards is by careful handling of them to minimise build up of dirt on them. It is important to pay particular attention, to only handle standards by the edges and not touch the front surface, to keep the standards in a closed box when not in use and to make sure that any surfaces such as instrument ports they are put up against are themselves clean.

6.1 Matt ceramic tiles and opal glasses

It is best to avoid getting matt tiles dirty by handling them as little as possible; wear clean cotton gloves, hold the tiles by the edges and always keep them in a closed box to prevent accumulation of dust etc. on them when not being used. Matt tiles are abrasive and should not be put against dark surfaces, e.g. black paint, as the surface might rub off onto the tile. Measurement ports should be protected with thin white non-fluorescent paper.

If cleaning is necessary, then it should start with the lowest level of cleaning and progress up a level if the tiles remain dirty. The simplest level is to use filtered (carbon + 22 μm paper) compressed air to remove dust and particles from the surface of the standard. The compressed air should be filtered to ensure that no oil that may be in it from the compressing process reaches the standard.

For heavily soiled matt tiles ethanol or propanol should be applied with a soft brush, and followed, while still wet, with a dilute non-fluorescent detergent, again applied with a soft brush. The tile should then be rinsed in warm running tap water for at least 1 minute followed by running deionised or distilled water for at least 1 minute. The tile should be shaken and then blown with filtered compressed air to remove excess water and left for at least 24 hours to dry. If results are unsatisfactory then the above process should be repeated using a more concentrated detergent solution, followed with washing in warm running tap water for ten minutes, and then running distilled water for 1 minute, then dry as before. After this type of heavy cleaning it is recommended that the tile be recalibrated if it is used as a standard.

6.2 Glossy ceramic tiles and opal glasses

Glossy tiles can be cleaned by firstly using filtered compressed air to remove dust. Secondly by breathing on them and rubbing in a circular motion with clean lens tissue or a clean soft tissue. This should be alternated until breathing produces a uniform breath pattern.

If they become very dirty then, before the above procedure is followed, they should be cleaned first with lens tissue or a soft tissue soaked in ethanol or propanol, followed by rinsing in deionised or distilled water for 1 minute and drying with a soft tissue.

6.3 PTFE based standards

There are a number of PTFE based standards available from various manufacturers. These included such products as Spectralon®, Fluorilon®, Zenith®, halon etc. As with other standards the simplest level of cleaning is to use filtered compressed air to remove dust and particles from the surface of the standard. If a heavier cleaning is needed then the cleaning procedure is to remove the top surface to expose a fresh clean surface.

For all standards except those with a reflectance of less than 10%, sand with a circular motion under running water using a 220 – 240 grit emery cloth wrapped round a sanding block. Sand until the surface is totally hydrophobic (water beads run off immediately). Then blow dry with filtered compressed air, or allow the material to air dry. For standards with a reflectance less than 10%, the procedure is the same except that the standards are sanded dry.

Further Reading

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For readers wanting more information on colour measurement the following may be useful:-

Measuring colour, R W G Hunt, 3rd Edition, Fountain Press, Kingston-upon-Thames UK (1998).
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