BS ISO 17321-1:2012

BSI Standards Publication

Graphic technology and photography — Colour characterisation of digital still cameras (DSCs)

Part 1: Stimuli, metrology and test procedures

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National foreword

This British Standard is the UK implementation of ISO 17321-1:2012. It supersedes BS ISO 17321-1:2006 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee CPW/42, Photography.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Part 1: **Stimuli, metrology and test procedures**

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Partie 1: Stimuli, métrologie et modes opératoires d'essai

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 17321-1 was prepared by Technical Committee ISO/TC 42, *Photography,* in collaboration with ISO/TC 130, *Graphic technology*.

This second edition cancels and replaces the first edition (ISO 17321-1:2006), of which it constitutes a minor revision with the following changes:

— in 4.3.3.4.2, the typographical error “senor image area” was corrected to “sensor image area”;

— in B.2.6, a broken link to tools for non-linear optimization has been updated.

ISO 17321 consists of the following parts, under the general title *Graphic technology and photography — Colour characterization of digital still cameras (DSCs)*:

— *Part 1: Stimuli, metrology and test procedures*

— *Part 2: Considerations for determining scene analysis transforms* [Technical Report]

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Introduction

The spectral responses of the colour analysis channels of digital still cameras (DSCs) do not, in general, match those of a typical human observer, such as defined by the CIE standard colorimetric observer. Nor do the responses of different DSCs ordinarily match each other. In characterizing DSCs, it is therefore necessary to take account of the DSC spectral sensitivities, illumination, and encoding colour space. This part of ISO 17321 will begin to address these considerations. This part of ISO 17321 defines stimuli (spectral illumination or a colour target), metrology and photographic test procedures for acquiring DSC characterization data. It specifies test procedures for "scenes", the most general picture taking conditions where metameric colours and a range of illumination sources are encountered. It also specifies test procedures for hardcopy "originals", a more narrowly defined picture-taking condition in which the illumination source and the colorants being imaged are pre-defined.

ISO 17321 will distinguish among several possible image representations in different colour encodings as depicted in Figure 1 which shows the diagram of a generic image workflow for digital photography.

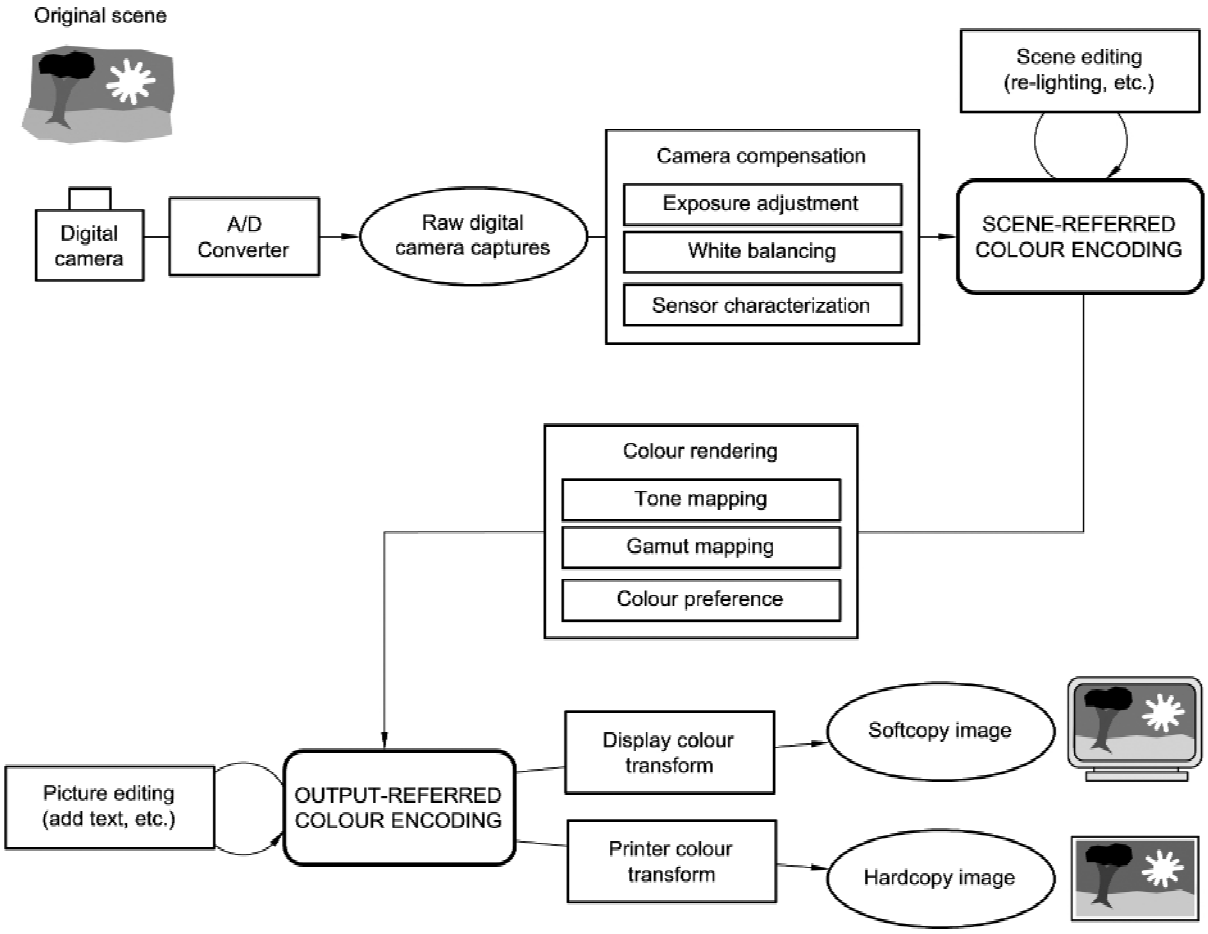

Figure 1 — Generic image workflow for digital photography

The DSC characterizations obtained using this part of ISO 17321 will be applicable to raw (sensor-referred) DSC data. Two alternative methods are described for obtaining these characterization data. Method A, the spectral method, uses spectral lights as stimuli for measuring the colour performance of a DSC. Method B, the target method, involves the use of a physical colour test target under specific lighting conditions to measure DSC colour performance. Annexes A to C recommend a laboratory set-up for photographing reflection targets, provide target patch selection criteria, and provide a digital still camera metamerism index.

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Some operations (colour pixel reconstruction, flare removal, white balancing) can be performed without disqualifying the DSC data as being raw. However, operations that render the image data so that they become output-referred (ready to display or to print) generally do disqualify the data. With such cameras, this standard can only be applied if the capability exists to extract or to regenerate raw data, e.g. by applying the inverse of the rendering transform or by tapping the appropriate signals internal to the camera.

The technical experts who have developed this part of ISO 17321 recognize that a standard that could be applied generally to any (not just raw) DSC output would be desirable. Such a standard is problematic for DSCs that employ colour-rendering algorithms in order to produce output-referred image data. For such DSCs, it would frequently be impossible to determine if colour analysis errors relative to the scene or original captured were due to sensor image encoding errors or to proprietary colour rendering algorithms. The only way to make this distinction is if the colour rendering used is well documented and available, and the rendered data can be converted to un-rendered data by inverting the colour rendering. This situation is unlikely to occur because one of the major differentiators in DSC performance is the colour rendering. Sophisticated colour-rendering algorithms can be image dependent, and locally varying within an image. This makes it extremely difficult to reliably determine the exact colour rendering used by analysing captured test scenes.

The purpose of this part of ISO 17321 is both to assist in the characterization of DSCs for colour management purposes and to assist camera manufacturers in the determination of the colour analysis capabilities of DSCs that they are developing. This standard is applicable to any DSC intended for photographic or graphic technology applications. However, for many users it is not practical to apply this part of ISO 17321 to individual DSCs. Some of the measurements described in this part of ISO 17321 require complex, expensive measurement equipment. In the case of test targets that are commercially produced, spectral as well as colorimetric measurement data would ideally accompany the target.

Those unfamiliar with this part of ISO 17321 are encouraged to read through the entire standard (in particular the informative annexes) before proceeding with DSC characterization, in order to verify appropriateness for their particular application. In some cases, the procedures described in the multimedia standard, IEC 61966-9[5] might be more applicable.

It is proposed that other parts of ISO 17321 will be developed in the future to deal with other aspects of the colour characterization of digital still cameras.

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Graphic technology and photography — Colour characterisation of digital still cameras (DSCs) —

Part 1: Stimuli, metrology and test procedures

1 Scope

This part of ISO 17321 specifies colour stimuli, metrology, and test procedures for the colour characterization of a digital still camera (DSC) to be used for photography and graphic technology. Two methods are provided, one using narrow spectral band illumination and the other using a spectrally and colorimetrically calibrated target. Except for a specific set of permitted data operations, these DSC data are raw.

This part of ISO 17321 does not specify the methods for deriving transformations from raw DSC data in order to estimate scene colorimetry.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7589, *Photography — Illuminants for sensitometry — Specifications for daylight, incandescent tungsten and printer*

ISO 13655, *Graphic technology — Spectral measurement and colorimetric computation for graphic arts images*

ISO 14524:2009, *Photography — Electronic still-picture cameras — Methods for measuring opto-electronic conversion functions (OECFs)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
adopted white
spectral radiance distribution as seen by an image capture or measurement device and converted to colour signals that are considered to be perfectly achromatic and to have an observer adaptive luminance factor of unity; i.e. colour signals that are considered to correspond to a perfect white diffuser

[ISO 22028-1]

NOTE 1 The adopted white can vary within a scene.

NOTE 2 No assumptions can be made concerning the relation between the adapted or adopted white and measurements of near perfectly reflecting diffusers in a scene, because measurements of such diffusers will depend on the illumination and viewing geometry, and other elements in the scene that can affect perception.

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3.2
digital still camera
DSC
device that incorporates an image sensor and that produces a digital signal representing a still picture

NOTE A digital still camera is typically a portable, hand-held device. The digital signal is usually recorded on a removable memory, such as a solid-state memory card or magnetic disk.

3.3
opto-electronic conversion function
OECF
relationship between log of input levels and corresponding digital output levels for an opto-electronic digital image capture system

NOTE If the input log exposure points are very finely spaced and the output noise is small compared to the quantization interval, the OECF possibly has a step-like character. Such behaviour is an artefact of the quantization process and needs to be removed by using an appropriate smoothing algorithm or by fitting a smooth curve to the data.

3.4
raw DSC image data
image data produced by, or internal to, a DSC that has not been processed, except for A/D conversion and the following optional steps:

- linearization,
- dark current/frame subtraction,
- shading and sensitivity (flat field) correction,
- flare removal,
- white balancing (e.g. so the adopted white produces equal RGB values or no chrominance),
- missing colour pixel reconstruction (without colour transformations)

3.5
spectrally non-selective
exhibiting reflective or transmissive characteristics that are constant over the wavelength range of interest

4 DSC colour characterization methods

4.1 General

Two methods are specified for obtaining raw DSC colour characterization data, a spectral method and a target method. The method that is most applicable in any particular situation depends on a variety of factors including, but not limited to, the following:

- the extent of one's prior knowledge about the spectral content of the scenes or originals to be captured;
- the equipment available;
- the accuracy required.

The spectral method requires elaborate equipment in a laboratory environment, but can be used to produce characterization data for samples with arbitrary spectral distributions. The target method is suitable for studio and field use, but can only provide accurate characterization data to the extent that the target spectral characteristics match those of the scene or original to be photographed.

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4.2 Spectral sensitivity-based characterization — Method A

4.2.1 Equipment

4.2.1.1 General

Spectral sensitivity-based characterization measurements shall be obtained by using a light source and monochromator to evenly illuminate a diffuse transmissive or reflective surface with electromagnetic radiation (light) containing a limited range of wavelengths centred on selected wavelengths, as specified in 4.2.3. Integrated relative radiance measurements of the illuminated surface shall be obtained for each selected wavelength using a radiance or irradiance meter with a spectral sensitivity calibration accurate to within 0,1 % and traceable to a national standards laboratory.

4.2.1.2 Light source

The light source shall output radiation where the power is a smooth function of the wavelength, such as that obtained from a quartz-halogen source. Light sources that have strong emission lines shall not be used.

NOTE A fluorescent lamp is a typical light source with strong emission lines.

4.2.1.3 Monochromator spectral sampling and band pass

The bandpass of the illuminating instrument (monochrometer) shall be 5 nm or narrower. The sampling interval shall not be greater than the bandpass. The monochromator should exhibit an approximately triangular band pass, with the full width at half-maximum wavelength range approximately equal to the sample spacing. The integrated radiance at all wavelengths more than 10 nm from the peak wavelength on which the monochromator is set shall be less than 1/1 000, and should be less than 1/10 000, of the integrated radiance within 10 nm of the peak radiance. Interference filters or a double monochromator may be used to meet this requirement.

4.2.1.4 Illuminated surface

The illuminated surface should be the interior of an integrating sphere. It is recommended to obtain an integrating sphere with three ports close together. A transmissive diffuser is placed over one port, and illuminated by the monochromator. This produces an even illumination on the interior of the sphere. The second port is for the DSC, and the third port is for the radiance or irradiance meter. Other evenly illuminated surfaces may be used, but it is the responsibility of the user to ensure such surfaces do not have characteristics that could influence the measurements. In all cases, stray light shall be prevented from entering the integrating sphere or camera.

NOTE 1 This can be achieved by carefully enclosing the integrating sphere with the camera attached with an opaque black fabric or plastic.

NOTE 2 The radiances produced for this measurement, and for the OECF measurement described in 4.2.3, need to be comparable to those encountered in the normal operation of the digital camera.

4.2.2 Camera settings

Fixed exposure settings shall be selected to provide peak output levels between 50 % and 90 % of saturation. Any automatic gain or adaptive tone reproduction (analog or digital) shall be disabled, compression shall be minimized, and all user settings shall be recorded. White balancing (analog or digital) shall be fixed, so that variations in white balance do not influence the measurements. Flash should be disabled to reduce the possibility of stray light.

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4.2.3 Capturing of raw images of the output of the monochromator

The procedure for capturing raw image data using Method A shall be as follows.

a) Use a monochromator to illuminate a diffuse transmitting or reflecting surface with light centred on selected wavelengths so the illuminated area is large enough to fill the field of view of the DSC. The radiance fall-off at the DSC focal plane should be even, constant as the monochromator peak wavelength is changed, and circularly symmetric with the radiance at the edge no less than 70 % of the radiance at the centre.

b) Use a radiance or irradiance meter to measure the relative radiance of the illuminated surface as a function of wavelength.

c) Capture images of the illuminated surface at wavelengths ranging from 360 nm to at least 830 nm, and preferably to 1 100 nm in 10 nm or smaller increments. The DSC shall be set up as described in ISO 14524 for alternative focal plane OECF measurements. The images shall be captured with the DSC lens and any filters used for general picture taking (such as an infrared blocking filter) in place. The data output by each colour analysis channel of the DSC shall remain independent, i.e. not be matrixed. The relative radiance of the surface shall also be recorded for each image. Where the DSC under test can be shown to have essentially no sensitivity at wavelengths within the above wavelength ranges, these ranges may be truncated appropriately.

d) Determine the alternative focal plane OECF of the DSC in accordance with ISO 14524, except that the measurement may be performed at the peak sensitivity wavelength for each colour analysis channel.

4.2.4 Post-processing of the data

Use the inverse alternative focal plane OECF to linearize the raw DSC responses at each wavelength. Average a 64 × 64 pixel block of values at the centre of each image to determine the linearized DSC response at each wavelength.

4.2.5 Calculation of the relative spectral sensitivities of the DSC

Calculate the relative spectral sensitivities at each wavelength for each colour analysis channel by dividing the linearized DSC response by the relative surface radiance. Optionally, DSC relative response values for various scene spectral radiances may be calculated by taking the scalar product of the spectral radiance and the spectral sensitivity vectors for each DSC colour channel (see Annex D for more information).

Normalize the spectral sensitivities so the sum of the green channel sensitivities is unity. A different channel may be normalized to unity if so reported.

NOTE If desired, the OECF of each channel, as measured in accordance with ISO 14524, can be used to determine absolute spectral sensitivities from the relative spectral sensitivities.

4.2.6 Data reporting

The data shall be reported in tabular form, with the relative spectral sensitivity reported for each channel at each selected wavelength.

4.3 Target-based characterization — Method B

4.3.1 General

The method to be used for the collection of target-based characterization data consists of imaging a reflective or transmissive colour target of known spectral and colorimetric characteristics, under

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specified illumination, recording the output of the DSC for each patch, and providing these data for subsequent processing.

NOTE When target-based characterization is used, the resultant characterization data is only applicable for similar geometric and spectral illumination characteristics.

4.3.2 Test target

The choice of test target to be used shall be a decision of the individual doing the characterization and may be a commercially available target or a custom target developed for the purpose of digital still camera characterization. Annex C provides a listing of some of the characteristics that should be considered in developing an ideal target for DSC characterization.

Regardless of the target used it shall have available a tabulation of the spectral reflectance factor or spectral transmittance factor for each patch. This data shall be from at least 380 nm to 730 nm at least at every 10 nm and should be from 360 nm to 830 nm at least at every 10 nm. In addition, colorimetric values for all of the colour patches should be included. Measurements and computation of colorimetric parameters shall be in accordance with ISO 13655. The use of telephoto-spectrometer from the identical position where the camera is set is preferred.

Where the DSC under test can be shown to have essentially no sensitivity at wavelengths within the above wavelength ranges, the target measurement requirements may be truncated appropriately.

NOTE 1 Two commonly available commercial targets that many have used for this application are the traditional 24 patch ColorChecker and the 237 patch ColorChecker DC Digital Camera Color Reference Chart. (ColorChecker is the trade name of a product supplied by GretagMacbeth. This information is given for the convenience of users of this part of ISO 17321 and does not constitute an endorsement by ISO of the product named. Equivalent products can be used if they can be shown to lead to the same results.)

NOTE 2 If measurements are not performed to 830 nm, there is a possibility that unwanted IR sensitivity will not be identified during subsequent testing. One approach is to separately look at the transmittance of any UV and IR blocking filters, the basic DSC filters, and the response of the detector itself. Another approach is illustrated by the example in ISO 14524 which provides a method for evaluating the sensitivity of a DSC to IR radiation.

4.3.3 Test procedure

4.3.3.1 Test target illumination

4.3.3.1.1 For laboratory characterization using a reflection target

The spectral power distribution for illuminating the test target shall be photographic daylight D55, as defined in ISO 7589. The illuminance at the target plane should be between 2 000 lx and 4 000 lx and have a maximum variation of 1 % over the area being imaged. Annex A outlines a recommended laboratory set-up for photographing a colour reflection test target.

The primary axis of the incident illumination should be approximately 45° to the normal to the centre of the target area being imaged. Two or more illumination sources, which are equally spaced around the normal to the centre of the area of the target that is being measured, should be used.

NOTE With the optical axis of the DSC normal to the test target, this will help to minimize the probability of specular reflections entering the field of view of the DSC.

In qualifying the illumination source, particular attention should be paid to the rolloff in red response. The spectral distribution index (SDI) described in ISO 7589 assumes a rolloff in red response which is normal with silver halide films, but does not naturally occur with typical DSC sensors. If a DSC has a long wavelength red response that is significantly different from that assumed in ISO 7589, the SDI criterion is possibly not sufficient for qualifying the illumination source. ISO 14524:2009, Annex B, also contains information about the relevancy of SDI calculations to the qualification of illumination sources for DSCs. If there is some question about the relevancy of the SDI, the illumination source used should be

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chosen so that its spectral power distribution matches that of the desired source as closely as possible, in addition to meeting the SDI criterion.

If it is determined that an IR blocking filter is required for OECF determination, in accordance with ISO 14524, the long wavelength red and infrared response of the DSC should be checked to determine if the response is being appropriately dealt with by the DSC's filters. If the DSC shows abnormally high long wavelength red response (see the standard red rolloff in ISO 7589), or significant near infrared response, additional filters can be used with the DSC at all times. It is also possible that the illumination source can be emitting excessive amounts of infrared radiation, in which case the IR blocking filter should be placed on the source, and the source requalified. If measurements of the DSC spectral response to wavelengths from 840 nm to 1 100 nm were obtained, these spectral response values can be used to further qualify the infrared rejection of the DSC. The ratio of the sum of spectral responses from 360 nm to 730 nm to the sum of spectral responses from 740 nm to 1 100 nm should be greater than the ISO DSC luminance dynamic range, as measured in accordance with ISO 15739[3].

4.3.3.1.2 For *in situ* characterization

When the DSC is to be characterized *in situ*, the illumination source to be used for actual imaging shall be used. This can be the digital still camera's own illumination, studio illumination, backlighting for transparent targets, or natural light (either artificial or daylight).

Where possible, the primary axis of the incident illumination for a reflection target should be approximately 45° to the normal to the centre of the target area being imaged. Two or more illumination sources, which are equally spaced around the normal to the centre of the area of the target that is being measured, should be used.

NOTE Placing the optical axis of the DSC normal to the surface of a reflection test target will help to minimize the probability of specular reflections entering the field of view of the DSC.

4.3.3.2 Camera focusing

The target distance is dictated by the size of the target, the field of view of the camera, and the focal length(s) of the camera lens. These should be chosen such that the DSC is in sharp focus for the resulting target distance.

4.3.3.3 Camera settings

For DSC characterizations performed in laboratory settings, the flash shall be turned off, any automatic gain control shall be disabled, compression shall be minimized, and all user settings shall be recorded. If possible, any digital white balancing should be turned off and any analog white balancing should be fixed, so that variations in the analog white balance do not confound the white balance of the raw DSC data revealed by the OECFs.

For DSC characterizations performed *in situ*, compression shall be minimized, and all user settings shall be recorded. While local conditions can require the use of automatic gain control, if possible it should be disabled. If possible, any digital white balancing should be turned off and any analog white balancing should be fixed, so that variations in the analog white balance do not confound the white balance of the raw DSC data revealed by the OECFs.

4.3.3.4 Image capture geometry

4.3.3.4.1 Full frame image capture

If full frame image capture is to be used, the test target should be framed within the DSC field of view so that the set of fiducial marks appropriate for the aspect ratio of the DSC end up just inside the corners of the captured image.

NOTE In the case of *in situ* characterization, the target can, of necessity, occupy a smaller portion of the captured image.

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4.3.3.4.2 Individual patch capture

If individual patch image capture is to be used, a black mask shall be used that has an aperture equal to the size of an individual patch. The DSC or target shall be moved such that one patch at a time is seen by the DSC at the centre of the image sensor area.

NOTE Individual patch capture can be used to minimize the effects of flare in the image capture step.

4.3.3.5 Data collection

Multiple images of the colour target, or individual patches, shall be recorded. These shall be analysed to derive average DSC digital code values for each channel corresponding to each patch. In selecting sensor element values to average, only those elements that are within the central 50 % of the area (70 % in linear dimensions) of the image of each patch shall be included. At least, (64 × 64) pixels should be used to analyse image data. Averaging shall be accomplished both within images and between at least three DSC image capture samples.

4.3.3.6 Data reporting

Data reported shall include at least the following:

— make, model, serial number, etc., of target used;

— measured or reported spectral reflectance/transmittance factor of each patch;

— computed colorimetry of each individual test patch for photographic daylight D55 and any other illumination used for testing;

— measured spectral power distribution of actual illumination source used;

— make, model, serial number, etc., of DSC(s) used for the test;

— mean and standard deviation of DSC code values corresponding to each patch;

— summary of DSC settings at time of image capture;

— DSC OECF used for analysis;

— capture geometry.

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Annex A
(informative)

Recommended laboratory set-up for photographing a reflection colour test target

A.1 General prerequisites

Three general prerequisites should be addressed in setting up a laboratory for photographing the colour test target:

a) accurate positioning of the camera with respect to the test target;

b) proper illumination of the target;

c) capturing of essential data.

A.2 Camera positioning

A well-designed system for positioning cameras will accomplish the following objectives:

— optical axis of camera perpendicular to the target plane;

— optical axis of camera intersects centre of target;

— no skewing of target relative to image sensor;

— no keystoning of target relative to image sensor;

— easy to mount cameras in a repeatable fashion;

— easy to adjust shooting distance to fill camera's field-of-view.

A.3 Target illumination

A well-designed system for illuminating the test target will accomplish the following objectives:

— simulated photographic daylight, or else spectral power distribution should be specified;

— geometry same as for measurement of spectral radiances reaching the camera;

— no specular reflections within the camera's field-of-view;

— uniform illuminance at the target plane;

— direct illumination of the target, with negligible secondary contribution from scattered or reflected light;

— regulated lamp voltage, with fixed level of direct current;

— easy way to confirm that the correlated colour temperature and illuminance at the target plane are at their aim values.

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A.4 Data acquisition

A well-designed system for acquiring data from images and for any associated metadata will accomplish the following objectives:

— computer with adequate memory, DSC interfaces, and a visual display;

— means of downloading images from camera or from removable memory media;

— means of extracting statistical data from captured digital images;

— means of extracting metadata tags pertaining to camera make and/or model settings;

— means of recording all data into a tab-delimited text document;

— means of archiving all images with their associated measurements.

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Annex B
(informative)

Digital still camera/sensitivity metamerism index (DSC/SMI)

B.1 General

In order to guarantee the colorimetric reproduction, a set of camera sensitivity curves is required to obey the Luther condition[12], which requires a linear transformation of colour matching functions. In practice, however, camera sensitivity curves deviate from the condition due to production reasons of filters, sensor and optical elements. Such a camera will reproduce different sensor outputs for two objects having the same tristimulus values but different spectral distributions.

DSC/SMIs are designed to give a measure for such potential colour error using the framework of CIE Publication 13[6]. The indices consist of an average DSC/SMI and a special DSC/SMI.

Average DSC/SMI will give a measure of camera metamerism for ordinary reflective objects. In this index, eight colour patches, defined in CIE Publication 13, represent reflective objects. Although a small number of colour patches are used, simulations using ISO/TR 16066[4] verify that the average DSC/SMI has a high correlation coefficient.

Special DSC/SMI is an optional measure by defining arbitrary objects depending on applications. Although average DSC/SMI will give a statistically reasonable measure, the measure may not be reliable for special objects such as highly saturated objects, fluorescent objects, and self-emitting colours. Special DSC/SMI allows users to specify arbitrary objects in order to optimize for a specific application. For instance, appropriate types of objects may be chosen from ISO/TR 16066.

Both measures give figures with the maximum of 100. The meaning of both indices is similar to the one defined in CIE Publication 13. The colour mismatch indicated by a DSC/SMI value will be comparable to the colour mismatch corresponding to the same colour rendering index value as defined in CIE Publication 13. An index of 100 means that there is a very close match to the Luther condition. An index of 50 corresponds approximately to the difference in colour rendering between D65 and a warm white fluorescent (WWF) light source.

Both indices can be measured through either spectral basis (Method A) or test target basis (Method B) as specified in Clause 4. Method B, however, can only be applied to a camera that can output linear processing signals such as sensor raw data. On the other hand, Method B requires test targets having appropriate spectral reflectances.

B.2 Measurement of DSC/SMIs using Method A

B.2.1 Step 1: Measurement of camera spectral sensitivities

Measure *j* channels of spectral sensitivities in accordance with 4.2.

IEC 61966-9[5] provides an alternate procedure that can be used where the requirements of 4.2 cannot be fully met.

B.2.2 Step 2: Selection of light source

Assign an appropriate light source. Illuminant D55 should be used as default.

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B.2.3 Step 3: Calculation of sensor outputs and tri-stimulus values

Calculate tristimulus values X_i, Y_i, Z_i, and sensor outputs $O_{I,i}$, $O_{2,i}$,..., $O_{j,i}$ using the following equations. Here, $R_i(\lambda)$ is one of the spectral reflectances of colour patches, and $s_j(\lambda)$ is the sensitivity of the jth channel (j < 8). The spectral reflectances of the colour patches for average DSC/SMI and the spectral distribution of the light source are listed in Table B.1.

Tristimulus values are calculated by the following equations:

$$X_i = K \sum_{\lambda=380}^{780} L(\lambda) R_i(\lambda) \bar{x}(\lambda) \tag{B.1}$$

$$Y_i = K \sum_{\lambda=380}^{780} L(\lambda) R_i(\lambda) \bar{y}(\lambda) \tag{B.2}$$

$$Z_i = K \sum_{\lambda=380}^{780} L(\lambda) R_i(\lambda) \bar{z}(\lambda) \tag{B.3}$$

where

$$K = \frac{100}{\sum_{\lambda=380}^{780} L(\lambda) \bar{y}(\lambda)} \tag{B.4}$$

$L(\lambda)$ is the light source;

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are colour matching functions.

Sensor outputs are calculated by the following equation:

$$O_{j,i} = \sum_{\lambda=380}^{780} L(\lambda) R_i(\lambda) s_j(\lambda) \tag{B.5}$$

Here, a spectral range from 380 nm to 780 nm with a 10 nm increment is suggested.

NOTE j is restricted to less than eight because only eight patches are used from CIE Publication 13[6].

B.2.4 Step 4: Calculation of linearly optimized colour matrix

Calculate the tentatively optimized linear matrix using Equation (B.6):

$$\boldsymbol{A} = \boldsymbol{TS}^{\mathrm{T}} \left(\boldsymbol{SS}^{\mathrm{T}} \right)^{-1} \tag{B.6}$$

where

$$\boldsymbol{T} = \begin{bmatrix} X_1 & \cdots & X_i & \cdots & X_8 \\ Y_1 & \cdots & Y_i & \cdots & Y_8 \\ Z_1 & \cdots & Z_i & \cdots & Z_8 \end{bmatrix} \tag{B.7}$$

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$$\boldsymbol{S} = \begin{bmatrix} O_{1,1} & \cdots & O_{1,i} & \cdots & O_{1,8} \\ \vdots & & \vdots & & \vdots \\ O_{j,1} & \cdots & O_{j,i} & \cdots & O_{j,8} \end{bmatrix} \tag{B.8}$$

A new set of estimated tristimulus values is calculated using:

$$\boldsymbol{T}_k = \boldsymbol{A}\boldsymbol{S}_k \tag{B.9}$$

where

$$\boldsymbol{T}_k = \begin{bmatrix} X_k \\ Y_k \\ Z_k \end{bmatrix} \tag{B.10}$$

and

$$\boldsymbol{S}_k = \begin{bmatrix} O_{1,k} \\ \vdots \\ O_{j,k} \end{bmatrix} \tag{B.11}$$

A measure for a system having more than three channels (e.g. complementary colour filter set such as CMYG) may not be realized due to practical processing limitations. In such a case, a set of three composite channels should be evaluated.

B.2.5 Step 5: Calculations of average DSC/SMI and special DSC/SMI

Calculate average DSC/SMI and special DSC/SMI as follows using the following equations:

$$L_{r,i}^* = 116\left(\frac{Y_{r,i}}{Y_r}\right)^{\frac{1}{3}} - 16 \tag{B.12}$$

$$a_{r,i}^* = 500\left\{\left(\frac{X_{r,i}}{X_r}\right)^{\frac{1}{3}} - \left(\frac{Y_{r,i}}{Y_r}\right)^{\frac{1}{3}}\right\} \tag{B.13}$$

$$b_{r,i}^* = 200\left\{\left(\frac{Y_{r,i}}{Y_r}\right)^{\frac{1}{3}} - \left(\frac{Z_{r,i}}{Z_r}\right)^{\frac{1}{3}}\right\} \tag{B.14}$$

$$L_{k,i}^* = 116\left(\frac{Y_{k,i}}{Y_k}\right)^{\frac{1}{3}} - 16 \tag{B.15}$$

$$a_{k,i}^* = 500\left\{\left(\frac{X_{k,i}}{X_k}\right)^{\frac{1}{3}} - \left(\frac{Y_{k,i}}{Y_k}\right)^{\frac{1}{3}}\right\} \tag{B.16}$$

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$$b_{k,i}^{*} = 200\left\{\left(\frac{Y_{k,i}}{Y_k}\right)^{\frac{1}{3}} - \left(\frac{Z_{k,i}}{Z_k}\right)^{\frac{1}{3}}\right\} \tag{B.17}$$

Colour difference ΔE is calculated by the following equation:

$$\Delta E_{\mathrm{ab},i}^{*} = \left\{\left(L_{r,i}^{*} - L_{k,i}^{*}\right)^2 + \left(a_{r,i}^{*} - a_{k,i}^{*}\right)^2 + \left(b_{r,i}^{*} - b_{k,i}^{*}\right)^2\right\}^{\frac{1}{2}} . \tag{B.18}$$

where

X_k, Y_k, Z_k	are the estimated tristimulus values of white (light source);
X_r, Y_r, Z_r	are the real tristimulus values of white (light source);
$L_{k,i}^{*}, a_{k,i}^{*}, b_{k,i}^{*}, X_{k,i}, Y_{k,i}, Z_{k,i}$	are the estimated L^*, a^*, b^* and tristimulus values of test target i;
$L_{r,i}^{*}, a_{r,i}^{*}, b_{r,i}^{*}, X_{r,i}, Y_{r,i}, Z_{r,i}$	are the real L^*, a^*, b^* and tristimulus values of test target i.

Special DSC/SMI R_i and average DSC/SMI R_a are obtained by the following equations, respectively (note that the coefficient value of 5,5 is determined in order to align with CIE Publication 13[6]).

$$R_i = 100 - 5{,}5\Delta E_i \tag{B.19}$$

$$R_\mathrm{a} = \frac{1}{8}\sum_{i=1}^{8} R_i \tag{B.20}$$

B.2.6 Step 6: Non-linear optimization for Matrix A

Matrix A shall be optimized in a non-linear optimization technique in order to minimize the average DSC/SMI with the initial matrix of the linear optimization. The resultant R_{i-NL}, $R_{\mathrm{a}-NL}$ shall be used. Note that Excel sheet "DSC/SMI.xls", available from http://standards.iso.org/iso/17321 as part of the ISO17321-1-Tools_ver101.zip, can be used for the non-linear optimization with the Solver command.

B.3 Measurement of DSC/SMIs with Method B

B.3.1 Step 1: Capture of colour patches

Capture the CIE Publication 13[6] eight patches (and also arbitrary colour patches if necessary) as described in Clause 4.

NOTE A commonly available commercial source of such target patches that may be used for this application is the Munsell colour book. The Federal Institute for Materials Research and Testing (BAM) of Germany also offers reflection and transmissive test targets, accompanied by measurement data, meeting the requirements of CIE Publication 13[6]. This information is given for the convenience of users of this part of ISO 17321 and does not constitute an endorsement by ISO of these products.

B.3.2 Step 2: Calculation

Follow Step 3 to Step 5 as described in B.2. The data reported in 4.3.3.6 can be used for sensor output in Equation (B.5).

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B.4 Data reporting

Average DSC/SMI should be reported with a measurement method (Method A or B). If the illuminant differs from D55, the light source should be identified. When Method A is used, spectral range and spectral increment used in Equations (B.1) to (B.4) should be reported. When Method B is used, spectral distributions of objects and light source should be measured and reported.

Special DSC/SMIs should be reported with spectral distributions of sample objects in addition to the items required for average DSC/SMI.

Table B.1 — Spectral distribution of colour patches and D55 used for DSC/SMI

Wave-length nm	Spectral distribution								
	7,5R 6/4	5Y 6/4	5GY 6/8	2,5G 6/6	10BG 6/4	5PB 6/8	2,5P 6/8	10P 6/8	D55
380	0,219 0	0,070 0	0,065 0	0,074 0	0,295 0	0,151 0	0,378 0	0,104 0	32,58
390	0,249 8	0,089 5	0,070 0	0,093 5	0,309 5	0,268 0	0,513 3	0,177 3	40,26
400	0,255 5	0,109 8	0,072 8	0,114 5	0,313 3	0,405 8	0,550 8	0,323 5	59,04
410	0,251 5	0,118 0	0,073 8	0,123 8	0,318 8	0,489 0	0,558 3	0,455 5	67,98
420	0,244 0	0,121 0	0,073 8	0,128 3	0,326 0	0,516 5	0,560 0	0,487 5	70,75
430	0,236 5	0,122 0	0,073 0	0,135 0	0,334 3	0,531 0	0,555 3	0,481 3	70,58
440	0,229 5	0,123 0	0,073 0	0,144 5	0,345 8	0,544 3	0,543 5	0,461 8	84,95
450	0,224 5	0,126 5	0,074 0	0,161 3	0,360 3	0,554 8	0,521 3	0,438 5	96,75
460	0,220 0	0,131 0	0,077 3	0,187 3	0,381 3	0,553 3	0,487 8	0,412 3	100,09
470	0,216 0	0,138 3	0,086 0	0,229 3	0,402 5	0,540 5	0,448 5	0,381 8	100,34
480	0,214 0	0,150 5	0,109 5	0,281 0	0,414 5	0,518 3	0,407 5	0,351 8	101,81
490	0,216 0	0,174 3	0,148 5	0,331 0	0,418 3	0,487 3	0,363 0	0,324 3	98,99
500	0,222 3	0,207 3	0,197 3	0,368 8	0,413 0	0,450 0	0,325 0	0,299 3	100,36
510	0,225 8	0,240 5	0,240 8	0,389 3	0,402 8	0,413 5	0,301 0	0,282 8	100,61
520	0,225 3	0,259 3	0,279 5	0,394 0	0,388 8	0,376 8	0,282 5	0,269 5	100,61
530	0,227 3	0,266 8	0,337 5	0,384 8	0,372 0	0,341 3	0,265 8	0,256 3	103,42
540	0,236 8	0,272 3	0,388 3	0,366 3	0,352 8	0,309 0	0,257 8	0,250 5	102,47
550	0,253 3	0,282 3	0,398 0	0,340 8	0,331 0	0,279 0	0,258 8	0,254 3	102,49
560	0,272 3	0,299 0	0,379 5	0,311 8	0,308 0	0,253 0	0,259 5	0,263 8	100,02
570	0,299 3	0,320 5	0,348 8	0,279 8	0,283 8	0,234 0	0,256 0	0,271 8	97,63
580	0,341 8	0,334 5	0,315 3	0,246 5	0,259 5	0,224 8	0,255 3	0,278 5	96,89
590	0,389 0	0,340 5	0,285 3	0,213 8	0,232 8	0,221 0	0,270 8	0,297 5	92,60
600	0,423 0	0,341 8	0,264 3	0,185 8	0,210 0	0,220 0	0,303 0	0,349 0	94,14
610	0,441 8	0,341 8	0,252 0	0,169 3	0,194 3	0,220 0	0,343 5	0,433 5	94,94
620	0,449 8	0,340 5	0,241 0	0,160 0	0,185 5	0,223 3	0,376 3	0,526 5	93,86
630	0,451 0	0,338 8	0,229 3	0,154 0	0,180 0	0,233 0	0,399 8	0,601 3	91,16
640	0,451 0	0,337 8	0,220 3	0,150 8	0,176 0	0,244 5	0,419 8	0,647 0	91,66
650	0,450 3	0,336 0	0,216 3	0,148 3	0,175 0	0,257 5	0,437 5	0,675 0	89,47
660	0,450 8	0,333 8	0,219 5	0,148 3	0,175 5	0,268 0	0,451 5	0,692 8	90,59
670	0,452 8	0,331 8	0,230 5	0,151 3	0,180 0	0,277 5	0,461 8	0,704 8	93,00
680	0,455 3	0,330 8	0,252 3	0,158 0	0,186 0	0,283 3	0,468 0	0,712 0	89,17
690	0,458 3	0,329 0	0,289 3	0,165 0	0,192 0	0,291 0	0,473 3	0,717 0	81,36

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Table B.1 *(continued)*

Wave-length nm	Spectral distribution								
	7,5R 6/4	**5Y 6/4**	**5GY 6/8**	**2,5G 6/6**	**10BG 6/4**	**5PB 6/8**	**2,5P 6/8**	**10P 6/8**	**D55**
700	0,461 8	0,327 8	0,339 5	0,169 8	0,198 3	0,303 3	0,483 0	0,720 3	82,70
710	0,464 0	0,326 0	0,389 5	0,169 8	0,199 0	0,325 3	0,496 0	0,720 0	82,77
720	0,465 8	0,324 3	0,430 3	0,166 0	0,196 3	0,351 0	0,510 8	0,724 8	73,20
730	0,466 0	0,323 8	0,459 8	0,164 3	0,195 3	0,376 3	0,525 0	0,728 8	78,88
740	0,466 8	0,322 0	0,480 5	0,168 3	0,197 5	0,401 0	0,539 0	0,730 0	82,64
750	0,467 0	0,319 8	0,492 8	0,176 8	0,202 8	0,424 8	0,552 8	0,730 0	71,14
760	0,467 0	0,316 3	0,499 8	0,185 0	0,208 3	0,447 0	0,564 8	0,730 0	58,07
770	0,467 0	0,314 8	0,505 5	0,191 8	0,214 8	0,468 3	0,574 5	0,730 0	72,52
780	0,467 0	0,314 0	0,516 0	0,197 0	0,219 0	0,485 0	0,581 0	0,730 0	71,82

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Annex C
(informative)

Characterization target considerations

C.1 Physical characteristics

A rectangular shape with a 3:2 aspect ratio best fits the image area of a broad range of DSCs. Individual colour patches need to be large enough to allow accurate spectral measurements of them to be made (at least 6 mm × 6 mm for typical instruments), and to allow adequate sampling by the DSC (12 mm × 12 mm or larger at a typical chart capture distances). The complete target should be constructed so that it is rigid enough to be self supporting and flat when standing on edge and leaning against a vertical support.

Thin black grids may be used to demarcate the colour patches and to secure them to a physical support or substrate. However, if used, such grids

— should not interfere with measurements of the individual colour patches,

— should have very low reflectance,

— should not fluoresce,

— should not introduce specular reflections or flare,

— to avoid introducing extraneous reflected energy.

C.2 Designing an ideal DSC characterization target

C.2.1 General

Any target used for DSC characterization should meet the following two basic criteria.

a) Colour patches are representative of typical scene objects, or real-world objects; i.e. colours cannot be reproduced by metamers (e.g. process colour printers or RGB displays).

b) Colours are widespread to adequately cover all regions of the colour gamut.

In addition, there are a number of other characteristics useful to include. These characteristics, their selection criteria, and recommendations that facilitate meeting the two criteria listed above are described in C.2.2 to C.2.11.

C.2.2 Extended neutral scale

It is important to include at least 12, and preferably 21 neutral grey patches. These neutral patches should cover an L^* range of at least 12 to 92, and be approximately equally spaced in steps of L^*. The C^* of each patch should be less than 2. In addition, the reflectance of these patches should be generally constant over the range of 350 nm to 1 100 nm.

NOTE 1 ISO 14524 describes the method used to measure the opto-electronic conversion function (OECF) of a DSC.

NOTE 2 The background ideally has the same characteristics as one of the neutral patches defined, which is positioned close to the centre of the target.

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C.2.3 Hue-lightness-chroma combinations

A series of patches can be used to represent a hue-lightness-chroma mapping, in CIELAB, of scene colour space. At each hue-angle three lightness levels are recommended. At each hue-angle and lightness, three chroma patches are also recommended. One at maximum chroma, of the selected colour space, for that hue-angle lightness combination and two others at approximately 2/3 and 1/3 of the achieved chroma of the related maximum-chroma patch. Table C.1 lists one set of recommended lightness and maximum chroma aims.

Table C.1 — Set of recommended lightness and maximum chroma aim combinations

Hue angle degrees	**Recommended combinations of lightness and maximum chroma aims versus hue-angle**					
	*L**	*C**	*L**	*C**	*L**	*C**
0	15	49	50	83	85	26
30	15	51	50	88	85	34
60	30	57	65	107	85	59
90	30	47	65	91	90	113
120	30	50	70	97	90	47
150	15	39	50	88	85	45
180	15	47	50	85	85	36
210	15	38	50	73	85	35
240	15	37	50	68	85	33
270	10	38	40	73	80	35
300	20	98	50	77	80	38
330	10	58	40	95	80	38

C.2.4 High-gloss colour patches

Care should be taken to avoid high-gloss colour patches to the extent possible. Where high-gloss patches are necessary to achieve the desired levels of chroma, they should be identified and grouped to facilitate elimination of specular reflections, and covered when not needed.

C.2.5 Special colours

In characterization targets, it is useful to include spectral radiances of common or critical natural objects, such as human skin, foliage, flowers, and sky, as found in natural environments. However, such radiances are not always reproducible in coloured patches, and this is one reason spectral characterization data can be useful. Annex D briefly describes the use of spectral characterization data, and provides some example spectral radiance measurements.

C.2.6 Infrared rejection test patch

A patch whose reflectance or transmittance is less than 3 % at all wavelengths between 360 nm and 650 nm and greater than 60 % at all wavelengths between 750 nm and 1 000 nm should be included to allow quick estimation of the effectiveness of DSC infrared rejection.

C.2.7 Target background

The background of the target should be spectrally non selective and approximately equal to an *L** of 50. It ideally would have the same characteristics as one of the neutral patches positioned close to the centre of the target. It should extend at least three patch widths beyond any colour patches and be large enough to include fiducial marks to designate image capture boundaries for aspect ratios of 16:9; 3:2; 4:3 and 1:1. Fiducial marks need to be at least two patch widths beyond any colour patches. This surround area

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can be used to verify or correct for non-uniformities, e.g. due to lighting conditions or vignetting by the DSC. It also should be adequately large to completely fill the field of view of any DSC being tested.

C.2.8 Other optical properties

Materials used in the fabrication of the test target should have negligible fluorescence. To ensure adequate lightfastness, preferably only ASTM category 1 as defined in ASTM D4303[8] materials are used.

C.2.9 Fiducial marks and identifying information

Fiducial marks to designate image capture boundaries for aspect ratios of 16:9; 3:2; 4:3 and 1:1 need to be included and located as defined in C.2.6. All targets should also carry identifying information including the identity of the manufacturer, and the date and batch number of manufacture.

C.2.10 Reflectance measurements of the colour target

As required in 4.3.2, all test targets will be accompanied by either target-specific or batch measurements of patch reflectances or transmittances covering the wavelength range of 380 nm to 730 nm. If DSC infrared sensitivity is a concern, it may be helpful to provide extended measurements to 1 000 nm. In addition, colorimetric values for all of the colour patches are helpful. ISO 13655 is a useful guide to the measurement and calculation of colorimetric data. Measurements provided should be identified as target specific or batch measurements.

C.2.11 Target map

A table that provides a mapping between target physical location and the data identifiers used to tabulate the spectral and colorimetric data of the target is essential for the efficient use of a target.

C.3 Target implementation based on using a minimum number of patches

In some situations the number of patches, and/or target size, is limited. A set of 24 patches having reflectance curves that match the data shown in Tables C.2 and C.3 are suggested for use in such situations.

NOTE A 24 patch Macbeth Color Checker provides patches that approximate these reflectances.

Table C.2 — Suggested spectral curves 1 to 12

Wave-length nm	Reflectance values for spectral curve											
	1	2	3	4	5	6	7	8	9	10	11	12
380	0,048	0,103	0,113	0,048	0,123	0,110	0,053	0,099	0,096	0,101	0,056	0,060
385	0,051	0,120	0,138	0,049	0,152	0,133	0,054	0,120	0,108	0,115	0,058	0,061
390	0,055	0,141	0,174	0,049	0,197	0,167	0,054	0,150	0,123	0,135	0,059	0,063
395	0,060	0,163	0,219	0,049	0,258	0,208	0,054	0,189	0,135	0,157	0,059	0,064
400	0,065	0,182	0,266	0,050	0,328	0,252	0,054	0,231	0,144	0,177	0,060	0,065
405	0,068	0,192	0,300	0,049	0,385	0,284	0,054	0,268	0,145	0,191	0,061	0,065
410	0,068	0,197	0,320	0,049	0,418	0,303	0,053	0,293	0,144	0,199	0,061	0,064
415	0,067	0,199	0,330	0,050	0,437	0,314	0,053	0,311	0,141	0,203	0,061	0,064
420	0,064	0,201	0,336	0,050	0,446	0,322	0,052	0,324	0,138	0,206	0,062	0,064
425	0,062	0,203	0,337	0,051	0,448	0,329	0,052	0,335	0,134	0,198	0,063	0,064
430	0,059	0,205	0,337	0,052	0,448	0,336	0,052	0,348	0,132	0,190	0,064	0,064
435	0,057	0,208	0,337	0,053	0,447	0,344	0,052	0,361	0,132	0,179	0,066	0,065
440	0,055	0,212	0,335	0,054	0,444	0,353	0,052	0,373	0,131	0,168	0,068	0,065

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Table C.2 *(continued)*

Wave-length nm	Reflectance values for spectral curve											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
445	0,054	0,217	0,334	0,056	0,440	0,363	0,052	0,383	0,131	0,156	0,071	0,066
450	0,053	0,224	0,331	0,058	0,434	0,375	0,052	0,387	0,129	0,144	0,075	0,067
455	0,053	0,231	0,327	0,060	0,428	0,390	0,052	0,383	0,128	0,132	0,079	0,068
460	0,052	0,240	0,322	0,061	0,421	0,408	0,052	0,374	0,126	0,120	0,085	0,069
465	0,052	0,251	0,316	0,063	0,413	0,433	0,052	0,361	0,126	0,110	0,093	0,073
470	0,052	0,262	0,310	0,064	0,405	0,460	0,053	0,345	0,125	0,101	0,104	0,077
475	0,053	0,273	0,302	0,065	0,394	0,492	0,054	0,325	0,123	0,093	0,118	0,084
480	0,054	0,282	0,293	0,067	0,381	0,523	0,055	0,301	0,119	0,086	0,135	0,092
485	0,055	0,289	0,285	0,068	0,372	0,548	0,056	0,275	0,114	0,080	0,157	0,100
490	0,057	0,293	0,276	0,070	0,362	0,566	0,057	0,247	0,109	0,075	0,185	0,107
495	0,059	0,296	0,268	0,072	0,352	0,577	0,059	0,223	0,105	0,070	0,221	0,115
500	0,061	0,301	0,260	0,078	0,342	0,582	0,061	0,202	0,103	0,067	0,269	0,123
505	0,062	0,310	0,251	0,088	0,330	0,583	0,064	0,184	0,102	0,063	0,326	0,133
510	0,065	0,321	0,243	0,106	0,314	0,580	0,068	0,167	0,100	0,061	0,384	0,146
515	0,067	0,326	0,234	0,130	0,294	0,576	0,076	0,152	0,097	0,059	0,440	0,166
520	0,070	0,322	0,225	0,155	0,271	0,569	0,086	0,137	0,094	0,058	0,484	0,193
525	0,072	0,310	0,215	0,173	0,249	0,560	0,101	0,125	0,091	0,056	0,516	0,229
530	0,074	0,298	0,208	0,181	0,231	0,549	0,120	0,116	0,089	0,054	0,534	0,273
535	0,075	0,291	0,203	0,182	0,219	0,535	0,143	0,110	0,090	0,053	0,542	0,323
540	0,076	0,292	0,198	0,177	0,211	0,519	0,170	0,106	0,092	0,052	0,545	0,374
545	0,078	0,297	0,195	0,168	0,209	0,501	0,198	0,103	0,096	0,052	0,541	0,418
550	0,079	0,300	0,191	0,157	0,209	0,480	0,228	0,099	0,102	0,053	0,533	0,456
555	0,082	0,298	0,188	0,147	0,207	0,458	0,260	0,094	0,106	0,054	0,524	0,487
560	0,087	0,295	0,183	0,137	0,201	0,436	0,297	0,090	0,108	0,055	0,513	0,512
565	0,092	0,295	0,177	0,129	0,196	0,414	0,338	0,086	0,109	0,055	0,501	0,534
570	0,100	0,305	0,172	0,126	0,196	0,392	0,380	0,083	0,112	0,054	0,487	0,554
575	0,107	0,326	0,167	0,125	0,199	0,369	0,418	0,083	0,126	0,053	0,472	0,570
580	0,115	0,358	0,163	0,122	0,206	0,346	0,452	0,083	0,157	0,052	0,454	0,584
585	0,122	0,397	0,160	0,119	0,215	0,324	0,481	0,085	0,208	0,052	0,436	0,598
590	0,129	0,435	0,157	0,115	0,223	0,302	0,503	0,086	0,274	0,053	0,416	0,609
595	0,134	0,468	0,153	0,109	0,229	0,279	0,520	0,087	0,346	0,055	0,394	0,617
600	0,138	0,494	0,150	0,104	0,235	0,260	0,532	0,087	0,415	0,059	0,374	0,624
605	0,142	0,514	0,147	0,100	0,241	0,245	0,543	0,086	0,473	0,065	0,358	0,630
610	0,146	0,530	0,144	0,098	0,245	0,234	0,552	0,085	0,517	0,074	0,346	0,635
615	0,150	0,541	0,141	0,097	0,245	0,226	0,560	0,084	0,547	0,086	0,337	0,640
620	0,154	0,550	0,137	0,098	0,243	0,221	0,566	0,084	0,567	0,099	0,331	0,645
625	0,158	0,557	0,133	0,100	0,243	0,217	0,572	0,085	0,582	0,113	0,328	0,650
630	0,163	0,564	0,130	0,100	0,247	0,215	0,578	0,088	0,591	0,126	0,325	0,654
635	0,167	0,569	0,126	0,099	0,254	0,212	0,583	0,092	0,597	0,138	0,322	0,658

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Table C.2 *(continued)*

Wave-length nm	Reflectance values for spectral curve											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
640	0,173	0,574	0,123	0,097	0,269	0,210	0,587	0,098	0,601	0,149	0,320	0,662
645	0,180	0,582	0,120	0,096	0,291	0,209	0,593	0,105	0,604	0,161	0,319	0,667
650	0,188	0,590	0,118	0,095	0,318	0,208	0,599	0,111	0,607	0,172	0,319	0,672
655	0,196	0,597	0,115	0,095	0,351	0,209	0,602	0,118	0,608	0,182	0,320	0,675
660	0,204	0,605	0,112	0,095	0,384	0,211	0,604	0,123	0,607	0,193	0,324	0,676
665	0,213	0,614	0,110	0,097	0,417	0,215	0,606	0,126	0,606	0,205	0,330	0,677
670	0,222	0,624	0,108	0,101	0,446	0,220	0,608	0,126	0,605	0,217	0,337	0,678
675	0,231	0,637	0,106	0,110	0,470	0,227	0,611	0,124	0,605	0,232	0,345	0,681
680	0,242	0,652	0,105	0,125	0,490	0,233	0,615	0,120	0,605	0,248	0,354	0,685
685	0,251	0,668	0,104	0,147	0,504	0,239	0,619	0,117	0,604	0,266	0,362	0,688
690	0,261	0,682	0,104	0,174	0,511	0,244	0,622	0,115	0,605	0,282	0,368	0,690
695	0,271	0,697	0,103	0,210	0,517	0,249	0,625	0,115	0,606	0,301	0,375	0,693
700	0,282	0,713	0,103	0,247	0,520	0,252	0,628	0,116	0,606	0,319	0,379	0,696
705	0,294	0,728	0,102	0,283	0,522	0,252	0,630	0,118	0,604	0,338	0,381	0,698
710	0,305	0,745	0,102	0,311	0,523	0,250	0,633	0,120	0,602	0,355	0,379	0,698
715	0,318	0,753	0,102	0,329	0,522	0,248	0,633	0,124	0,601	0,371	0,376	0,698
720	0,334	0,762	0,102	0,343	0,521	0,244	0,633	0,128	0,599	0,388	0,373	0,698
725	0,354	0,774	0,102	0,353	0,521	0,245	0,636	0,133	0,598	0,406	0,372	0,700
730	0,372	0,783	0,102	0,358	0,522	0,245	0,637	0,139	0,596	0,422	0,375	0,701
735	0,392	0,788	0,104	0,362	0,521	0,251	0,639	0,149	0,595	0,436	0,382	0,701
740	0,409	0,791	0,104	0,364	0,521	0,260	0,638	0,162	0,593	0,451	0,392	0,701
745	0,420	0,787	0,104	0,360	0,516	0,269	0,633	0,178	0,587	0,460	0,401	0,695
750	0,436	0,789	0,104	0,362	0,514	0,278	0,633	0,197	0,584	0,471	0,412	0,694
755	0,450	0,794	0,106	0,364	0,514	0,288	0,636	0,219	0,584	0,481	0,422	0,696
760	0,462	0,801	0,106	0,368	0,517	0,297	0,641	0,242	0,586	0,492	0,433	0,700
765	0,465	0,799	0,107	0,368	0,515	0,301	0,639	0,259	0,584	0,495	0,436	0,698
770	0,448	0,771	0,110	0,355	0,500	0,297	0,616	0,275	0,566	0,482	0,426	0,673
775	0,432	0,747	0,115	0,346	0,491	0,296	0,598	0,294	0,551	0,471	0,413	0,653
780	0,421	0,734	0,120	0,341	0,487	0,296	0,582	0,316	0,540	0,467	0,404	0,639

Table C.3 — Suggested spectral curves 13 to 24

Wave-length nm	Reflectance values for spectral curve											
	13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
380	0,069	0,055	0,052	0,054	0,118	0,093	0,153	0,150	0,138	0,113	0,074	0,032
385	0,081	0,056	0,052	0,053	0,142	0,110	0,189	0,184	0,167	0,131	0,079	0,033
390	0,096	0,057	0,052	0,054	0,179	0,134	0,245	0,235	0,206	0,150	0,084	0,033
395	0,114	0,058	0,052	0,053	0,228	0,164	0,319	0,299	0,249	0,169	0,088	0,034
400	0,136	0,058	0,051	0,053	0,283	0,195	0,409	0,372	0,289	0,183	0,091	0,035
405	0,156	0,058	0,051	0,053	0,322	0,220	0,536	0,459	0,324	0,193	0,093	0,035

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Table C.3 *(continued)*

Wave-length nm	Reflectance values for spectral curve											
	13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
410	0,175	0,059	0,050	0,053	0,343	0,238	0,671	0,529	0,346	0,199	0,094	0,036
415	0,193	0,059	0,050	0,052	0,354	0,249	0,772	0,564	0,354	0,201	0,094	0,036
420	0,208	0,059	0,049	0,052	0,359	0,258	0,840	0,580	0,357	0,202	0,094	0,036
425	0,224	0,060	0,049	0,052	0,357	0,270	0,868	0,584	0,358	0,203	0,094	0,036
430	0,244	0,062	0,049	0,053	0,350	0,281	0,878	0,585	0,359	0,203	0,094	0,036
435	0,265	0,063	0,049	0,053	0,339	0,296	0,882	0,587	0,360	0,204	0,095	0,036
440	0,290	0,065	0,049	0,053	0,327	0,315	0,883	0,587	0,361	0,205	0,095	0,035
445	0,316	0,067	0,049	0,054	0,313	0,334	0,885	0,588	0,362	0,205	0,095	0,035
450	0,335	0,070	0,049	0,055	0,298	0,352	0,886	0,588	0,362	0,205	0,095	0,035
455	0,342	0,074	0,048	0,056	0,282	0,370	0,886	0,587	0,361	0,205	0,094	0,035
460	0,338	0,078	0,048	0,059	0,267	0,391	0,887	0,586	0,361	0,204	0,094	0,035
465	0,324	0,084	0,047	0,065	0,253	0,414	0,888	0,585	0,359	0,204	0,094	0,035
470	0,302	0,091	0,047	0,075	0,239	0,434	0,888	0,583	0,358	0,203	0,094	0,035
475	0,273	0,101	0,046	0,093	0,225	0,449	0,888	0,582	0,358	0,203	0,093	0,035
480	0,239	0,113	0,045	0,121	0,209	0,458	0,888	0,581	0,357	0,202	0,093	0,034
485	0,205	0,125	0,045	0,157	0,195	0,461	0,888	0,580	0,356	0,202	0,093	0,034
490	0,172	0,140	0,044	0,202	0,182	0,457	0,888	0,580	0,356	0,202	0,093	0,034
495	0,144	0,157	0,044	0,252	0,172	0,447	0,888	0,580	0,356	0,202	0,092	0,034
500	0,120	0,180	0,044	0,303	0,163	0,433	0,887	0,580	0,356	0,202	0,092	0,034
505	0,101	0,208	0,044	0,351	0,155	0,414	0,887	0,580	0,356	0,202	0,093	0,034
510	0,086	0,244	0,044	0,394	0,146	0,392	0,887	0,580	0,356	0,202	0,093	0,034
515	0,074	0,286	0,044	0,436	0,135	0,366	0,887	0,581	0,356	0,202	0,093	0,034
520	0,066	0,324	0,044	0,475	0,124	0,339	0,887	0,581	0,357	0,202	0,093	0,034
525	0,059	0,351	0,044	0,512	0,113	0,310	0,887	0,582	0,357	0,202	0,093	0,034
530	0,054	0,363	0,044	0,544	0,106	0,282	0,887	0,582	0,357	0,203	0,093	0,034
535	0,051	0,363	0,044	0,572	0,102	0,255	0,887	0,582	0,358	0,203	0,093	0,034
540	0,048	0,355	0,045	0,597	0,102	0,228	0,887	0,583	0,358	0,203	0,093	0,034
545	0,046	0,342	0,046	0,615	0,105	0,204	0,886	0,583	0,358	0,203	0,093	0,034
550	0,045	0,323	0,047	0,630	0,107	0,180	0,886	0,583	0,358	0,203	0,093	0,034
555	0,044	0,303	0,048	0,645	0,107	0,159	0,887	0,584	0,358	0,203	0,092	0,034
560	0,043	0,281	0,050	0,660	0,106	0,141	0,887	0,584	0,359	0,203	0,093	0,033
565	0,042	0,260	0,053	0,673	0,107	0,126	0,887	0,585	0,359	0,203	0,093	0,033
570	0,041	0,238	0,057	0,686	0,112	0,114	0,888	0,586	0,360	0,204	0,093	0,033
575	0,041	0,217	0,063	0,698	0,123	0,104	0,888	0,587	0,361	0,204	0,093	0,033
580	0,040	0,196	0,072	0,708	0,141	0,097	0,887	0,588	0,361	0,205	0,093	0,033
585	0,040	0,177	0,086	0,718	0,166	0,092	0,886	0,588	0,361	0,205	0,093	0,033
590	0,040	0,158	0,109	0,726	0,198	0,088	0,886	0,588	0,361	0,205	0,093	0,033
595	0,040	0,140	0,143	0,732	0,235	0,083	0,886	0,588	0,361	0,205	0,092	0,033
600	0,039	0,124	0,192	0,737	0,279	0,080	0,887	0,588	0,360	0,204	0,092	0,033

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Table C.3 *(continued)*

Wave-length nm	Reflectance values for spectral curve											
	13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
605	0,039	0,111	0,256	0,742	0,333	0,077	0,888	0,587	0,360	0,204	0,092	0,033
610	0,040	0,101	0,332	0,746	0,394	0,075	0,889	0,586	0,359	0,204	0,092	0,033
615	0,040	0,094	0,413	0,749	0,460	0,074	0,890	0,586	0,358	0,203	0,091	0,033
620	0,040	0,089	0,486	0,753	0,522	0,073	0,891	0,585	0,357	0,203	0,091	0,033
625	0,040	0,086	0,550	0,757	0,580	0,073	0,891	0,584	0,356	0,202	0,091	0,033
630	0,041	0,084	0,598	0,761	0,628	0,073	0,891	0,583	0,355	0,201	0,090	0,033
635	0,041	0,082	0,631	0,765	0,666	0,073	0,891	0,581	0,354	0,201	0,090	0,033
640	0,042	0,080	0,654	0,768	0,696	0,073	0,890	0,580	0,353	0,200	0,090	0,033
645	0,042	0,078	0,672	0,772	0,722	0,073	0,889	0,579	0,352	0,199	0,090	0,033
650	0,042	0,077	0,686	0,777	0,742	0,074	0,889	0,578	0,351	0,198	0,089	0,033
655	0,043	0,076	0,694	0,779	0,756	0,075	0,889	0,577	0,350	0,198	0,089	0,033
660	0,043	0,075	0,700	0,780	0,766	0,076	0,889	0,576	0,349	0,197	0,089	0,033
665	0,043	0,075	0,704	0,780	0,774	0,076	0,889	0,575	0,348	0,197	0,088	0,033
670	0,044	0,075	0,707	0,781	0,780	0,077	0,888	0,574	0,346	0,196	0,088	0,033
675	0,044	0,077	0,712	0,782	0,785	0,076	0,888	0,573	0,346	0,195	0,088	0,033
680	0,044	0,078	0,718	0,785	0,791	0,075	0,888	0,572	0,345	0,195	0,087	0,033
685	0,044	0,080	0,721	0,785	0,794	0,074	0,888	0,571	0,344	0,194	0,087	0,033
690	0,045	0,082	0,724	0,787	0,798	0,074	0,888	0,570	0,343	0,194	0,087	0,032
695	0,046	0,085	0,727	0,789	0,801	0,073	0,888	0,569	0,342	0,193	0,087	0,032
700	0,048	0,088	0,729	0,792	0,804	0,072	0,888	0,568	0,341	0,192	0,086	0,032
705	0,050	0,089	0,730	0,792	0,806	0,072	0,887	0,567	0,340	0,192	0,086	0,032
710	0,051	0,089	0,730	0,793	0,807	0,071	0,886	0,566	0,339	0,191	0,086	0,032
715	0,053	0,090	0,729	0,792	0,807	0,073	0,886	0,565	0,338	0,191	0,086	0,032
720	0,056	0,090	0,727	0,790	0,807	0,075	0,886	0,564	0,337	0,190	0,085	0,032
725	0,060	0,090	0,728	0,792	0,810	0,078	0,885	0,562	0,336	0,189	0,085	0,032
730	0,064	0,089	0,729	0,792	0,813	0,082	0,885	0,562	0,335	0,189	0,085	0,032
735	0,070	0,092	0,729	0,790	0,814	0,090	0,885	0,560	0,334	0,188	0,085	0,032
740	0,079	0,094	0,727	0,787	0,813	0,100	0,884	0,560	0,333	0,188	0,085	0,032
745	0,091	0,097	0,723	0,782	0,810	0,116	0,884	0,558	0,332	0,187	0,084	0,032
750	0,104	0,102	0,721	0,778	0,808	0,133	0,883	0,557	0,331	0,187	0,084	0,032
755	0,120	0,106	0,724	0,780	0,811	0,154	0,882	0,556	0,330	0,186	0,084	0,032
760	0,138	0,110	0,728	0,782	0,814	0,176	0,882	0,555	0,329	0,185	0,084	0,032
765	0,154	0,111	0,727	0,781	0,813	0,191	0,881	0,554	0,328	0,185	0,084	0,032
770	0,168	0,112	0,702	0,752	0,785	0,200	0,880	0,553	0,327	0,184	0,083	0,032
775	0,186	0,112	0,680	0,728	0,765	0,208	0,880	0,551	0,326	0,184	0,083	0,032
780	0,204	0,112	0,664	0,710	0,752	0,214	0,879	0,550	0,325	0,183	0,083	0,032

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Annex D
(informative)

Calculating natural scene element responses from spectral characterization data

D.1 General

Colour characterization data obtained using the methods described in this part of ISO 17321 are used for the determination of colour characterization transforms that are applied to raw data to convert it into scene-referred colour spaces, as described in ISO 22028-1. Methods for the determination of these transforms are proprietary. In some cases, target patch data are used. In other cases, DSC spectral characterization data are used directly, or are used to calculate what the DSC response would be to specific spectral radiance distributions. Then, the calculated responses for these "synthetic patches" are used to determine the characterization transforms.

D.2 Calculation of responses

The response of a DSC to a spectral radiance distribution can be calculated by simply taking the scalar product of the spectral radiance and the DSC spectral sensitivity for each channel, expressed as vectors. The resulting values predict what the response of the DSC would be to the spectral radiance distribution, within a scaling factor that depends on the overall amplitude of the spectral radiance, the DSC aperture and exposure time, and the sensitivity of the DSC, including the optics. The scaling factors may also be channel, and therefore white balance, dependent. It may therefore be necessary to normalize the response value produced relative to the response that would be produced by the adopted white (3.1), in order to determine the raw data that would be output by a camera if a specific spectral radiance distribution is captured using a specific adopted white.

D.3 Local illumination effects

When considering scene spectral radiances, it is useful to note that they may be the result of contributions from reflections (diffuse and specular), transmission, emission, scattering, fluorescence, etc. Also, in natural scenes, the local illumination contributing to a particular spectral radiance distribution may be quite different from what would be appropriate as the adopted white for the entire scene. For example, inter-reflections in foliage often result in significantly more infrared and green energy being present than is found in natural daylight. However, the DSC adopted white should usually not be set to match this local illumination when photographing the scene, because doing so is unlikely to track human visual system adaptation to the scene, and may result in an incorrect colour cast. Even if the adopted white is allowed to vary over the scene to track the local illumination, doing so may not result in a scene colour analysis that matches visual perception. It is generally better to correlate the adopted white with the overall scene illumination, rather than localized illumination. However, the adopted white may change over a scene due to variations in the overall illumination level and spectral distribution.

D.4 Example of spectral radiance values

Table D.1 provides relative spectral radiances of some common objects in their natural surroundings, and includes a reasonable adopted white spectral radiance distribution, that could be used in photographing the scene containing the measured elements.

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Table D.1 — Relative spectral radiances of some common objects

Wave-length nm	White refer-ence	Material													
		Red rose	Beg-onia	Ora-nge flower	Morn-ing glory flower (in shade)	Morn-ing glory leaf	Green apple	Apple leaf	Lilac leaf	Grass	Blue sky	Cau-casian skin	Red-dish Cau-casian skin	Blonde hair	Brown hair
380	0,031 2	0,001 6	0,000 3	0,004 1	0,000 3	0,002 9	0,001 5	0,000 3	0,004 9	0,000 9	0,038 4	0,008 2	0,005 4	0,004 6	0,006 9
385	0,033 4	0,001 4	0,000 4	0,003 9	0,000 3	0,003 1	0,001 5	0,000 4	0,005 3	0,000 9	0,039 0	0,009 6	0,005 8	0,005 2	0,007 3
390	0,037 1	0,002 0	0,000 5	0,005 0	0,000 4	0,003 5	0,001 7	0,000 6	0,005 8	0,001 0	0,041 6	0,011 2	0,006 7	0,006 1	0,008 1
395	0,040 9	0,002 1	0,000 6	0,005 7	0,000 6	0,003 8	0,001 7	0,000 7	0,006 3	0,001 3	0,043 3	0,013 1	0,007 4	0,007 3	0,009 0
400	0,052 9	0,002 2	0,000 9	0,007 4	0,000 9	0,005 2	0,002 1	0,000 8	0,008 0	0,001 7	0,052 7	0,017 1	0,009 7	0,010 3	0,011 6
405	0,062 4	0,002 3	0,001 4	0,008 4	0,001 3	0,006 4	0,002 4	0,001 0	0,009 7	0,002 3	0,059 7	0,020 5	0,011 7	0,013 3	0,014 1
410	0,066 9	0,002 6	0,001 7	0,008 8	0,001 8	0,007 3	0,002 5	0,001 2	0,010 4	0,002 7	0,060 9	0,022 3	0,012 6	0,015 7	0,015 3
415	0,070 6	0,002 9	0,002 0	0,008 8	0,002 3	0,008 1	0,002 6	0,001 3	0,011 0	0,003 0	0,061 0	0,023 7	0,013 5	0,017 8	0,016 4
420	0,070 8	0,003 2	0,002 2	0,009 0	0,002 8	0,008 7	0,002 5	0,001 3	0,011 3	0,003 2	0,058 8	0,024 1	0,013 9	0,019 5	0,016 8
425	0,068 7	0,003 1	0,002 2	0,007 8	0,003 2	0,009 0	0,002 4	0,001 2	0,011 5	0,003 3	0,054 5	0,024 3	0,014 0	0,020 7	0,016 9
430	0,066 5	0,002 9	0,002 1	0,007 1	0,003 5	0,009 2	0,002 5	0,001 3	0,011 8	0,003 3	0,050 5	0,024 8	0,014 2	0,021 6	0,016 7
435	0,069 7	0,003 0	0,002 1	0,007 7	0,004 0	0,009 9	0,002 8	0,001 4	0,012 8	0,003 5	0,050 4	0,027 8	0,015 5	0,024 2	0,017 8
440	0,076 0	0,003 2	0,002 2	0,008 1	0,004 6	0,011 1	0,003 2	0,001 5	0,014 6	0,003 8	0,052 8	0,032 6	0,017 8	0,027 9	0,019 8
445	0,080 7	0,003 2	0,002 2	0,007 9	0,005 1	0,012 1	0,003 6	0,001 6	0,016 1	0,004 2	0,053 8	0,037 1	0,019 8	0,031 3	0,021 6
450	0,084 1	0,003 2	0,002 2	0,008 4	0,005 5	0,012 9	0,004 0	0,001 7	0,017 3	0,004 5	0,054 0	0,041 5	0,021 7	0,034 6	0,023 1
455	0,086 1	0,003 0	0,002 1	0,009 1	0,005 8	0,013 2	0,004 3	0,001 8	0,018 1	0,004 8	0,053 3	0,045 0	0,023 1	0,037 5	0,024 2
460	0,087 7	0,003 1	0,002 0	0,009 7	0,005 9	0,013 7	0,004 4	0,001 8	0,018 7	0,004 9	0,052 2	0,048 2	0,024 4	0,039 9	0,025 1
465	0,088 5	0,003 1	0,001 9	0,010 6	0,005 9	0,013 9	0,004 5	0,001 8	0,019 0	0,005 1	0,050 8	0,050 8	0,025 4	0,042 1	0,026 0
470	0,087 7	0,003 0	0,001 7	0,011 2	0,005 7	0,013 9	0,004 5	0,001 7	0,019 1	0,005 1	0,048 6	0,052 4	0,026 1	0,043 6	0,026 5
475	0,088 2	0,002 8	0,001 5	0,011 8	0,005 5	0,014 1	0,004 4	0,001 7	0,019 4	0,005 2	0,047 0	0,054 7	0,027 0	0,045 8	0,027 3
480	0,088 9	0,002 6	0,001 3	0,012 5	0,005 2	0,014 2	0,004 4	0,001 7	0,019 7	0,005 3	0,045 5	0,057 0	0,027 9	0,048 1	0,028 2
485	0,086 2	0,002 7	0,001 2	0,013 6	0,004 7	0,013 8	0,004 3	0,001 7	0,019 3	0,005 2	0,042 9	0,056 9	0,027 8	0,048 4	0,028 0
490	0,085 2	0,002 8	0,001 0	0,015 5	0,004 4	0,013 8	0,004 3	0,001 7	0,019 3	0,005 3	0,041 0	0,058 0	0,028 2	0,049 5	0,028 3
495	0,086 6	0,002 8	0,000 9	0,017 4	0,004 2	0,014 1	0,004 6	0,001 7	0,020 0	0,005 6	0,040 3	0,061 0	0,029 5	0,051 9	0,029 3
500	0,085 0	0,002 5	0,000 8	0,019 6	0,003 8	0,014 1	0,004 9	0,001 7	0,020 1	0,006 0	0,038 3	0,061 9	0,029 7	0,052 6	0,029 5
505	0,084 0	0,002 5	0,000 7	0,025 5	0,003 4	0,014 3	0,005 5	0,001 7	0,020 8	0,006 6	0,036 4	0,063 0	0,030 0	0,053 7	0,029 7
510	0,083 5	0,002 5	0,000 7	0,034 1	0,003 1	0,015 0	0,006 3	0,001 9	0,022 1	0,007 6	0,035 0	0,064 0	0,030 3	0,054 9	0,030 2
515	0,081 4	0,002 5	0,000 6	0,042 0	0,002 8	0,015 7	0,007 1	0,002 2	0,023 8	0,008 8	0,033 0	0,063 0	0,029 5	0,054 8	0,029 9
520	0,080 9	0,002 5	0,000 6	0,049 2	0,002 6	0,017 5	0,008 1	0,002 5	0,027 1	0,010 5	0,031 6	0,062 4	0,028 9	0,055 7	0,030 2
525	0,083 6	0,002 5	0,000 6	0,055 7	0,002 5	0,020 8	0,009 6	0,003 1	0,033 0	0,013 2	0,031 5	0,063 2	0,028 8	0,058 9	0,031 8
530	0,085 2	0,002 6	0,000 6	0,059 4	0,002 4	0,023 9	0,010 8	0,003 7	0,038 7	0,015 6	0,030 9	0,062 8	0,028 2	0,061 2	0,033 0
535	0,085 7	0,002 6	0,000 6	0,061 8	0,002 2	0,026 1	0,011 6	0,004 1	0,043 0	0,017 2	0,030 1	0,061 8	0,027 5	0,062 9	0,033 9
540	0,085 0	0,002 6	0,000 6	0,063 0	0,002 0	0,027 2	0,011 9	0,004 4	0,045 7	0,018 0	0,029 0	0,060 6	0,026 8	0,063 9	0,034 2
545	0,084 6	0,002 5	0,000 6	0,065 3	0,001 8	0,027 8	0,012 2	0,004 6	0,047 5	0,018 6	0,027 9	0,060 7	0,026 8	0,065 0	0,034 7
550	0,085 3	0,002 7	0,000 8	0,069 4	0,001 7	0,028 6	0,012 5	0,004 7	0,049 5	0,019 2	0,027 2	0,062 7	0,027 6	0,067 0	0,035 7
555	0,084 6	0,002 8	0,000 8	0,073 1	0,001 5	0,028 3	0,012 4	0,004 7	0,049 5	0,019 0	0,026 3	0,063 8	0,028 2	0,067 7	0,036 0
560	0,083 2	0,002 7	0,001 0	0,077 8	0,001 4	0,027 2	0,012 0	0,004 5	0,047 9	0,018 4	0,025 1	0,064 3	0,028 2	0,068 0	0,036 2
565	0,082 5	0,002 7	0,001 2	0,085 4	0,001 3	0,025 7	0,011 5	0,004 1	0,045 1	0,017 4	0,024 2	0,064 4	0,027 8	0,068 9	0,036 7
570	0,081 4	0,002 8	0,001 6	0,096 8	0,001 2	0,023 7	0,010 7	0,003 7	0,041 3	0,015 9	0,023 1	0,063 2	0,026 8	0,069 7	0,037 1
575	0,081 2	0,002 9	0,002 1	0,111 0	0,001 1	0,021 9	0,010 0	0,003 3	0,037 9	0,014 6	0,022 3	0,062 2	0,026 1	0,071 1	0,037 9
580	0,081 9	0,003 4	0,002 8	0,129 0	0,001 0	0,020 6	0,009 5	0,003 0	0,035 5	0,013 6	0,021 9	0,064 4	0,026 7	0,073 4	0,039 2

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Table D.1 — ***(continued)***

Wavelength nm	White reference	Material													
		Red rose	Begonia	Orange flower	Morning glory flower (in shade)	Morning glory leaf	Green apple	Apple leaf	Lilac leaf	Grass	Blue sky	Caucasian skin	Reddish Caucasian skin	Blonde hair	Brown hair
585	0,081 5	0,004 4	0,004 0	0,148 3	0,001 0	0,019 5	0,009 2	0,002 9	0,033 5	0,012 8	0,021 3	0,070 6	0,029 5	0,074 5	0,039 8
590	0,079 4	0,006 1	0,005 4	0,167 0	0,000 9	0,018 2	0,008 6	0,002 6	0,031 2	0,011 9	0,020 0	0,078 9	0,035 3	0,074 0	0,039 5
595	0,079 5	0,009 3	0,007 2	0,189 5	0,000 9	0,017 8	0,008 5	0,002 5	0,030 4	0,011 5	0,019 5	0,089 4	0,044 3	0,075 5	0,040 2
600	0,079 7	0,013 8	0,009 5	0,212 0	0,000 9	0,017 5	0,008 4	0,002 5	0,029 9	0,011 2	0,019 1	0,098 3	0,053 9	0,077 3	0,041 2
605	0,080 0	0,020 6	0,012 2	0,232 8	0,001 0	0,017 2	0,008 3	0,002 4	0,029 4	0,011 0	0,018 9	0,106 0	0,062 7	0,079 4	0,042 3
610	0,078 6	0,029 5	0,015 0	0,248 5	0,001 1	0,016 3	0,007 9	0,002 3	0,027 9	0,010 4	0,018 2	0,110 0	0,069 2	0,080 1	0,042 7
615	0,077 3	0,040 2	0,017 5	0,259 8	0,001 2	0,015 5	0,007 5	0,002 1	0,026 3	0,009 8	0,017 4	0,113 3	0,073 7	0,080 5	0,043 0
620	0,076 5	0,052 8	0,019 9	0,270 0	0,001 4	0,014 8	0,007 1	0,002 0	0,025 1	0,009 3	0,016 9	0,116 0	0,077 5	0,081 3	0,043 5
625	0,075 4	0,067 6	0,021 7	0,275 5	0,001 7	0,014 4	0,006 8	0,001 9	0,024 1	0,008 9	0,016 1	0,118 0	0,080 1	0,081 6	0,043 8
630	0,074 1	0,085 2	0,023 2	0,278 5	0,002 3	0,014 0	0,006 6	0,001 8	0,023 5	0,008 6	0,015 4	0,119 0	0,081 9	0,081 6	0,044 0
635	0,074 3	0,104 8	0,024 6	0,284 5	0,003 0	0,013 8	0,006 5	0,001 8	0,023 2	0,008 4	0,015 1	0,122 3	0,084 7	0,083 2	0,044 9
640	0,074 5	0,126 0	0,025 8	0,290 0	0,003 8	0,013 6	0,006 2	0,001 7	0,022 6	0,007 8	0,015 0	0,125 0	0,087 6	0,085 1	0,046 1
645	0,073 5	0,146 3	0,026 1	0,288 8	0,004 9	0,013 0	0,005 6	0,001 6	0,021 2	0,007 1	0,014 4	0,125 0	0,088 2	0,085 1	0,046 2
650	0,072 3	0,166 0	0,026 1	0,286 5	0,006 0	0,012 4	0,005 1	0,001 5	0,020 2	0,006 4	0,013 8	0,124 5	0,088 6	0,084 9	0,046 4
655	0,070 7	0,184 3	0,025 9	0,282 8	0,006 9	0,012 0	0,004 7	0,001 4	0,019 1	0,006 0	0,013 3	0,124 0	0,088 6	0,084 6	0,046 5
660	0,071 5	0,209 0	0,026 4	0,288 0	0,008 1	0,012 0	0,004 4	0,001 4	0,018 7	0,005 8	0,013 2	0,127 0	0,091 4	0,087 2	0,048 0
665	0,072 4	0,233 8	0,027 0	0,293 3	0,009 0	0,012 0	0,003 9	0,001 4	0,018 4	0,005 6	0,013 2	0,131 3	0,094 4	0,090 1	0,049 9
670	0,072 0	0,251 0	0,027 0	0,293 0	0,009 6	0,012 0	0,003 6	0,001 4	0,018 1	0,005 3	0,012 9	0,132 0	0,095 5	0,091 2	0,050 8
675	0,071 4	0,265 3	0,026 8	0,291 3	0,009 9	0,012 0	0,003 4	0,001 4	0,018 1	0,005 2	0,012 5	0,132 8	0,096 2	0,092 0	0,051 4
680	0,070 1	0,276 0	0,026 4	0,287 0	0,010 2	0,012 1	0,003 6	0,001 4	0,018 1	0,005 3	0,012 0	0,132 0	0,095 8	0,091 8	0,051 5
685	0,066 7	0,271 3	0,025 1	0,271 5	0,010 1	0,012 0	0,004 1	0,001 5	0,018 4	0,005 7	0,011 0	0,125 5	0,091 6	0,087 7	0,049 4
690	0,064 9	0,270 5	0,024 3	0,261 5	0,010 2	0,012 9	0,005 7	0,001 8	0,020 5	0,007 4	0,010 2	0,122 0	0,089 2	0,085 3	0,048 1
695	0,067 2	0,286 3	0,025 2	0,268 0	0,011 3	0,016 4	0,008 7	0,002 6	0,027 7	0,011 4	0,010 3	0,126 0	0,092 6	0,088 4	0,049 8
700	0,069 6	0,299 0	0,025 9	0,274 0	0,012 6	0,022 8	0,012 9	0,004 3	0,041 2	0,017 6	0,010 3	0,129 0	0,095 9	0,091 4	0,051 6
705	0,071 5	0,309 0	0,026 6	0,278 0	0,014 2	0,031 6	0,018 0	0,007 1	0,060 3	0,025 2	0,010 3	0,131 5	0,098 5	0,093 6	0,052 8
710	0,073 0	0,314 5	0,026 9	0,279 0	0,015 8	0,041 8	0,023 6	0,010 9	0,082 5	0,033 7	0,010 3	0,132 0	0,099 8	0,094 9	0,053 6
715	0,071 2	0,300 5	0,025 7	0,263 5	0,016 9	0,051 2	0,028 2	0,015 0	0,101 7	0,041 2	0,009 5	0,125 0	0,095 0	0,090 5	0,051 3
720	0,068 3	0,281 0	0,023 9	0,243 0	0,018 0	0,059 6	0,032 2	0,019 5	0,118 0	0,048 2	0,008 5	0,115 0	0,088 7	0,084 4	0,047 9
725	0,069 4	0,280 5	0,023 9	0,241 0	0,020 2	0,070 4	0,038 5	0,025 9	0,140 0	0,059 6	0,008 3	0,114 5	0,089 1	0,084 5	0,048 1
730	0,073 2	0,294 0	0,025 1	0,251 0	0,023 5	0,083 6	0,047 1	0,034 8	0,168 0	0,076 1	0,008 7	0,119 0	0,093 5	0,088 7	0,050 7
735	0,078 0	0,313 5	0,026 9	0,267 0	0,026 9	0,095 6	0,056 0	0,044 2	0,196 0	0,094 2	0,009 5	0,125 8	0,099 9	0,095 1	0,054 4
740	0,080 8	0,326 0	0,028 0	0,276 0	0,029 5	0,104 0	0,063 1	0,052 3	0,216 0	0,110 0	0,009 9	0,129 0	0,103 0	0,099 4	0,057 3
745	0,082 7	0,332 8	0,028 8	0,281 3	0,031 8	0,110 8	0,068 9	0,059 4	0,229 8	0,124 3	0,010 4	0,131 3	0,106 3	0,102 3	0,058 9
750	0,083 1	0,333 5	0,028 8	0,279 5	0,032 9	0,113 5	0,071 9	0,063 5	0,235 5	0,133 0	0,010 6	0,131 0	0,106 0	0,102 5	0,059 7
755	0,077 6	0,308 8	0,026 6	0,258 3	0,031 2	0,106 5	0,068 5	0,061 3	0,221 0	0,128 3	0,010 2	0,120 3	0,097 3	0,095 9	0,055 9
760	0,059 3	0,228 0	0,019 7	0,190 0	0,023 9	0,081 4	0,051 7	0,046 8	0,165 0	0,098 3	0,008 0	0,089 1	0,071 8	0,071 5	0,042 0
765	0,063 2	0,240 5	0,020 5	0,199 3	0,025 9	0,086 8	0,055 2	0,050 4	0,172 5	0,105 5	0,008 3	0,093 8	0,076 0	0,075 6	0,044 4
770	0,077 3	0,301 0	0,025 8	0,248 0	0,032 1	0,105 8	0,069 7	0,063 5	0,215 5	0,132 5	0,010 5	0,116 5	0,095 4	0,095 1	0,056 3
775	0,084 7	0,329 3	0,028 3	0,273 5	0,035 0	0,115 0	0,077 2	0,070 4	0,237 5	0,147 3	0,012 0	0,127 8	0,104 3	0,105 0	0,062 7
780	0,085 6	0,330 0	0,028 5	0,274 0	0,035 3	0,115 0	0,078 3	0,071 0	0,238 0	0,149 0	0,013 0	0,128 0	0,105 0	0,107 0	0,064 2

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