TECHNICAL REPORT

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

Part 2: Considerations for determining scene analysis transforms

Technologie graphique et photographie — Caractérisation de la couleur des appareils photonumériques —

Partie 2: Considérations pour déterminer les transformations d'analyse de scène

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Foreword

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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.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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/TR 17321-2 was prepared by Technical Committee ISO/TC 42, *Photography*.

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*

Introduction

Digital still cameras (DSCs) have become the predominant means of photographic image capture, but the nature of the image data produced by different cameras, or even by the same camera operating in different modes, is quite variable. This variability can cause problems in workflows, miscommunications and interoperability issues.

This Technical Report provides information about methods for determining scene analysis transforms, which are transforms that convert raw image data to scene-referred image data. This information is provided in the form of a Technical Report because there are a number of choices to be made when determining scene analysis transforms. These choices are influenced by the subject matter being photographed (including the scene illumination), the scene adopted white and the adopted white of the scene-referred colour encoding to be used, aesthetic choices regarding scene analysis colour error minimization, and other considerations. It is not possible to provide more specific recommendations because the spectral responses of DSC colour analysis channels do not, in general, match those of a typical human observer, such as defined by a CIE standard colourimetric observer. Nor do the responses of different DSCs ordinarily match each other. This Technical Report outlines considerations relevant to the determination of scene analysis transforms based on the minimization of errors in specified colour spaces. The DSC characterization data obtained using ISO 17321-1 serve as the raw DSC image data.

Good understanding of this Technical Report requires that the three fundamental modes of DSC operation be distinguished: the raw mode, the scene-referred mode, and the output-referred mode. When operating in the raw mode, a DSC records image data that is most closely related to the sensor response. Some types of processing may have been performed, such as dark current subtraction, defect removal and colour filter array interpolation, but neither a scene analysis nor a colour rendering transform has been applied. Any encoding transform typically consists of only a non-linearity to better align the quantization intervals with the image noise characteristics, and possibly some form of compression.

When operating in the scene-referred mode, a DSC records image data that represents an estimate of the scene or focal plane image relative colourimetry, typically with white balancing to the encoding adopted white. The image data has not undergone colour rendering for some anticipated output medium and viewing conditions. In order to produce output-referred images intended for reproduction, it is necessary to either apply a colour rendering transform directly to the scene-referred images, or convert them to a working colour space where the desired colour rendering is applied. Camera controls or raw processing software can offer some aesthetic choices when converting to scene-referred, but the results of such choices need to be viewed through the intended colour rendering transform in order to see their effect on the final output. The image data are encoded prior to applying the colour rendering transform, and are therefore not an encoding of the intended output colourimetry. At present, few DSCs offer an in-camera scene-referred mode, although some camera raw processing applications have this capability.

When operating in the output-referred mode, the DSC controls are set to achieve the desired output directly, thereby incorporating the colour rendering, and in many cases a reference output device encoding (such as for a CRT monitor) in the image file. When operating in this mode the DSC encodes the colourimetry of the intended output on the reference medium, not scene-referred colourimetry. Also, the output-referred colourimetry can be in different encodings, with different reference media, and in some cases will need to be colour re-rendered and/or re-encoded to produce different reproductions.

The information provided in this Technical Report is intended to help camera and raw processing software manufacturers, professional photographers and colour measurement applications to determine, communicate about, and select DSC scene analysis transforms. However, it will often not be practical for end users to determine scene analysis transforms themselves. In addition to the requirement for raw DSC image data, relatively sophisticated and expensive measurement equipment is required to obtain chart patch spectral reflectance or radiance, illumination source spectral power, and DSC spectral sensitivity (as described in ISO 17321-1).

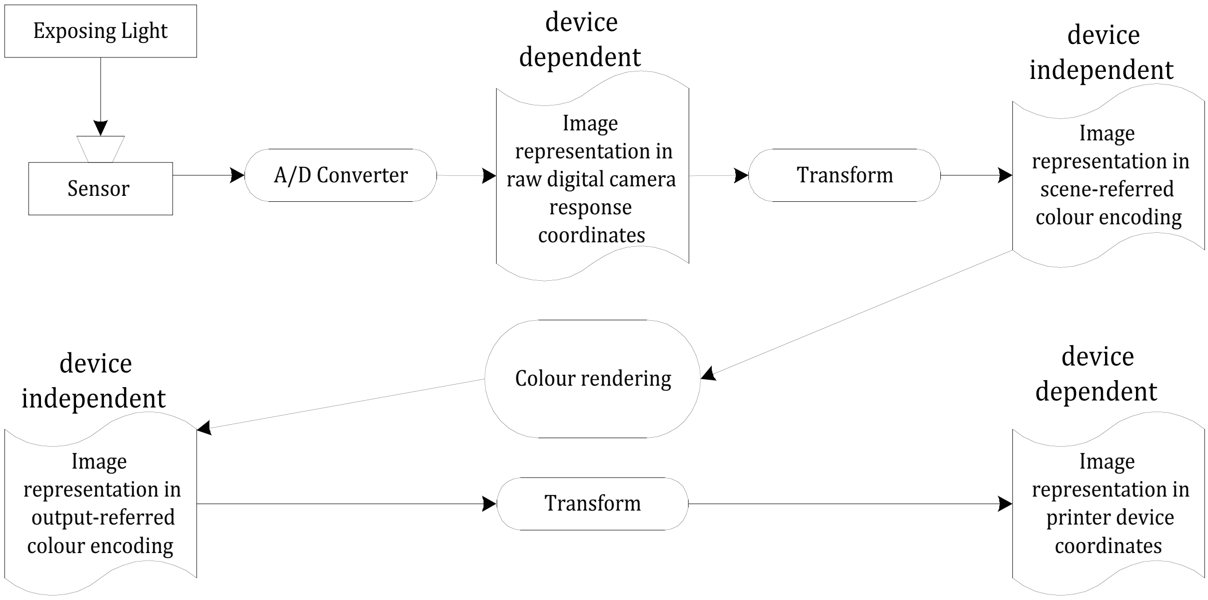

Figure 1 — Generic image workflow for digital photography

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

Part 2: Considerations for determining scene analysis transforms

1 Scope

This Technical Report provides information about methods for determining scene analysis transforms based on the minimization of errors in estimated scene or focal-plane colourimetry, including corresponding colourimetry. These transforms are limited in applicability to raw DSC image data.

This Technical Report concerns only the creation and encoding of scene-referred and focal-plane-referred image data. It does not address the encoding of output-referred image data. It also does not provide information relating to the specification of metadata items describing intended artistic adjustments, colour rendering and viewing.

This Technical Report does not address how to choose adopted white points or how to process scene-referred image data to produce output-referred image data.

This Technical Report is not intended to be comprehensive or complete; it is an overview intended to enable improved practices and communications.

2 Definitions

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

2.1
absolute colorimetric coordinates
tristimulus values, or other colorimetric coordinates derived from tristimulus values, where the numerical values correspond to the magnitude of the physical stimulus

EXAMPLE If the colourimetric coordinates used are CIE 1931 standard 2° observer tristimulus values, the Y value should correspond to the luminance, not the luminance factor (or some scaled value thereof).

2.2
adapted white
colour stimulus that an observer who is adapted to the viewing environment would judge to be perfectly achromatic and to have a luminance factor of unity; i.e. absolute colorimetric coordinates that an observer would consider to be a perfect white diffuser

NOTE 1 The adapted white can vary within a scene.

NOTE 2 No assumptions should be made concerning the relation between the adapted 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. It is easy to arrange conditions for which a near perfectly reflecting diffuser will appear to be grey or coloured.

NOTE 3 See adopted white (2.3).

2.3
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

NOTE 1 The adopted white can vary within a scene, if such variation is supported by the imaging system.

NOTE 2 The adopted white is not required to be an estimate or approximation of the adapted white. For example, if a scene lit by tungsten illumination is captured using a DSC with the white balance set to D55 (daylight), the adopted white will be D55 but the adapted white will be closer to a tungsten illuminant (e.g. ISO 7589 Studio Tungsten or CIE Illuminant A).

NOTE 3 See adapted white (2.2).

2.4
scene analysis transform spectral limit
mapping of spectral (monochromatic) colours as captured by a DSC and transformed to a scene-referred colour encoding using a specified scene analysis transform

2.5
colour component transfer function
CCTF
single variable, monotonic mathematical function applied individually to one or more colour channels of a colour space

NOTE 1 Colour component transfer functions are frequently used to account for the non-linear response of a reference device and/or to improve the visual uniformity of a colour space.

NOTE 2 Generally, colour component transfer functions will be non-linear functions such as a power-law (i.e. "gamma") function or a logarithmic function. However, in some cases a linear colour component transfer function will be used.

2.6
colour gamut
solid in a colour space, consisting of all those colours that are either: 1) present in a specific scene, artwork, photograph, photomechanical or other reproduction; 2) capable of being created using a particular output device and/or medium

NOTE See scene analysis transform spectral limit (2.4).

2.7
colour matching functions
tristimulus values of monochromatic stimuli of equal radiant power

[CIE Publication 17.4, 845-03-23]

2.8
colour pixel reconstruction
algorithm that creates a fully populated colour image record from the output of a colour filter array type sensor by interpolating values for each colour at each pixel location, also known as demosaicing or colour pixel interpolation

2.9
colour rendering
mapping of image data representing the colorimetric coordinates of the elements of a scene or original to image data representing the colorimetric coordinates of the elements of a reproduction

NOTE Colour rendering generally consists of one or more of the following: compensating for differences in the input and output viewing conditions, tone scale and gamut mapping to map the scene colours onto the dynamic range and colour gamut of the reproduction, and applying preference adjustments.

2.10
colour space
geometric representation of colours in space, usually of three dimensions

[CIE Publication 17.4, 845-03-25]

2.11
corresponding colorimetry
colorimetric coordinates for samples that produce a visual match with different viewer adaptation states

EXAMPLE Chromatic adaptation transforms estimate corresponding colourimetry for viewing conditions where only the adapted white chromaticity is different. Colour appearance models can be used to estimate corresponding colourimetry where more aspects of the viewing conditions are different. The colour appearance model is used to calculate appearance correlates for one viewing condition. The inverse of the colour appearance model is then used to calculate colourimetric coordinates for a second viewing condition from the colour appearance correlates.

2.12
digital still camera
DSC
device which incorporates an image sensor and which 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.

2.13
output-referred image data

image data which represents the colorimetric coordinates of the elements of an image that has undergone colour rendering appropriate for a specified real or virtual output device and viewing conditions

NOTE 1 The output referred image data are referred to the specified output device and viewing conditions. A single scene can be colour rendered to a variety of output-referred representations depending on the anticipated output viewing conditions, media limitations, and/or artistic intents.

NOTE 2 Output-referred image data can become the starting point for a subsequent reproduction process. For example, sRGB output-referred image data are frequently considered to be the starting point for the colour re-rendering performed by a printer designed to receive sRGB image data.

2.14
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 & 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)

NOTE See scene-referred image data (2.17).

2.15
scene
spectral radiances of a view of the natural world as measured from a specified vantage point in space and at a specified time

NOTE A scene can represent an actual view of the natural world or a simulation of such a view.

2.16
scene analysis transform
transform that converts raw DSC image data to scene-referred image data

2.17
scene-referred image data
image data which represents estimates of the colorimetric coordinates of the elements of a scene

NOTE 1 Scene-referred image data can be determined from raw DSC image data before colour rendering is performed. Generally, DSCs do not write scene-referred image data in image files, except possibly in a special mode intended for this purpose. Typically, DSCs write standard output-referred image data where colour rendering has already been performed.

NOTE 2 Scene-referred image data typically represents relative scene colourimetry estimates. Absolute scene colourimetry estimates can be calculated using a scaling factor. The scaling factor can be derived from additional information such as the image OECF, FNumber or ApertureValue, and ExposureTime or ShutterSpeedValue tags.

NOTE 3 Scene-referred image data can contain inaccuracies due to the dynamic range limitations of the capture device, noise from various sources, quantization, optical blurring and flare that are not corrected for, and colour analysis errors due to capture device metamerism. In some cases, these sources of inaccuracy can be significant.

NOTE 4 The transformation from raw DSC image data to scene-referred image data depends on the relative adopted whites selected for the scene and the colour space used to encode the image data. If the chosen scene adopted white is inappropriate, additional errors will be introduced into the scene-referred image data. These errors can be correctable if the transformation used to produce the scene-referred image data are known, and the colour encoding used for the incorrect scene-referred image data has adequate precision and dynamic range.

NOTE 5 The scene can correspond to an actual view of the natural world, or a simulation of such a view. It can also correspond to a modified scene determined by applying modifications to an original scene to produce some different desired scene. Any such scene modifications should leave the image in a scene-referred image state and should be done in the context of an expected colour rendering transform.

2.18
tristimulus values
amounts of the three reference colour stimuli, in a given trichromatic system, required to match the colour of the stimulus considered

[CIE Publication 17.4, 845-03-22]

NOTE See colour matching functions (2.7).

2.19
working colour space
colour space encoding in which operations such as image edits, enhancements or colour rendering are performed

NOTE 1 The image state in a working colour space can change as operations are performed.

NOTE 2 If operations performed in a working colour space are guided by viewing the image on a medium, that medium and the associated viewing conditions become the reference for the resulting image.

NOTE 3 See colour matching functions (2.7).

3 Goals

The goals of this Technical Report are as follows.

- To list the fundamental colour-related characteristics of DSCs.
- To document some methods and parameters used for the conversion of raw DSC image data to scene or focal plane colourimetry estimates
  - for the case where scene analysis transforms are determined using spectral measurements, and

- — for the case where scene analysis transforms are determined by capturing test targets.

— To provide recommendations for specifying the encoding of scene and focal plane colourimetry estimates.

— To provide recommendations for metadata to be included in scene-referred image files or other specified locations, communicating the colour-related characteristics of the capture device, the scene analysis transform used, and the colour encoding used.

4 Fundamental colour-related DSC characteristics

4.1 Camera gain

Camera gain is the ratio of the digital count obtained to the sensor exposure for the linear region of the sensor and analogue-to-digital converter response range.

— The sensor exposure can be either a photometric exposure or an integrated channel radiometric exposure, but different gains will typically result for each type of exposure.

— Neutral balance is achieved by adjusting the channel gains, either in analogue or digital processing.

— If the sensor or the encoding of the sensor signals is non-linear, the gain will be a function of the sensor exposure.

— Even for a sensor with inherently linear response, a non-linear encoding can be used to take advantage of noise statistics to reduce the bit-depth required to encode the sensor signals.

— In use, digital cameras can offer selectable gains or apply automatic gain control in attempt to maintain normal signal levels when different Exposure Indexes (EIs) are used. Likewise, selectable or automatic channel gains are typically used to achieve a satisfactory neutral balance. For the characterization of raw mode camera behaviour, the overall and channel-specific camera gains need to be fixed, i.e. any automatic gain and white balance needs to be disabled.

— Generally, automatic gain control is not applied when a camera is set to raw mode operation, to provide the maximum capture dynamic range. It is assumed that any desired overall gain or neutral balance will be applied later.

— Different gains applied to address the use of different EIs or neutral balances are applied to linear sensor signals, prior to any non-linear encoding.

4.2 Camera dark current

Camera dark current is the digital counts recorded in the absence of any sensor exposure.

— Dark current is typically a function of the sensor temperature and integration time.

— The dark current value can be an average over the sensor (or some area of the sensor), or can be determined on a per-pixel basis using dark frame exposures. However, it should be noted that since dark current is noisy, it is highly desirable to average multiple dark frames.

— Many cameras perform dark current subtraction in the analogue domain, before digitization, in which case the average digital dark current can be close to zero.

— Use of an encoding that supports negative values preserves the statistics of the dark current after subtraction.