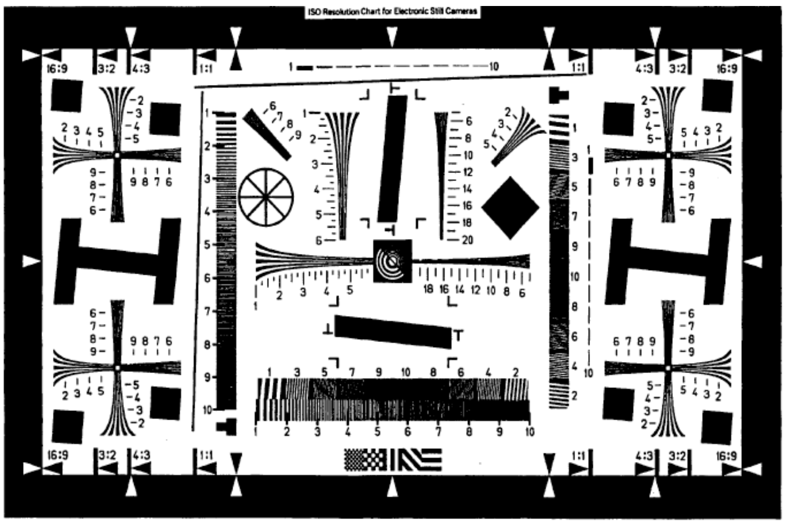
A Review of Standards Defining Testing Procedures for Characterizing the Color and Spatial Quality of Digital Cameras Used to Image Cultural Heritage



Technical Report
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MUNSELL COLOR SCIENCE LAB

The mission of the Munsell Color Science Laboratory is to advance the science, understanding, and technology of color and appearance through education, research, and outreach

Abstract

This standards review summarizes the most current standards, which can be used to define target-based testing procedures to characterize the image quality of trichromatic digital cameras that are used to image cultural heritage. The eighteen standards summarized here were developed by both national (ANSI and NISO) and international (ISO, IEC and CIE) standards organizations. The image quality parameters that these standards describe include tone reproduction, color reproduction accuracy, noise, resolution, spatial uniformity, dynamic range and image flare. Other standards describe monitor viewing conditions, illuminant specifications, ISO speed determination, electronic imaging terminology, colorimetry and technical metadata. Some of the standards summarized in this review also contain descriptions of test charts, which can be photographed and analyzed objectively, for the most part, for a specific image quality parameter.

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2. Introduction

For decades, museums, libraries, and other cultural heritage institutions have been using analog photography as a means for archiving their collections. Through the years, these institutions developed "best practices" for the process of archiving, which included photographing the object, storing the image, and cataloging, so that a high quality image archive could be obtained and maintained for many years.

Now that digital photography is well established and comparable to analog photography, these cultural heritage institutions have a choice of whether to continue archiving the traditional way or start archiving using digital technology. The process of digital archiving requires a shared vocabulary and standardized evaluation of system performance and digital output (Kenney, 2000). The purpose of this standard review is to describe the most current standards that define mostly objective testing procedures, including the use of test targets, or charts, which can be applied to the characterization of trichromatic digital cameras used to digitally capture cultural heritage collections, in particular, three-dimensional objects (e.g. paintings and sculptures). These testing procedures can be used to benchmark camera systems and procedures currently used for digital archiving by the cultural heritage community. The benchmarking of camera systems is performed by relating the quality of the digital reproduction to the physical characteristics of the original. Benchmarking systems will help to compare different camera systems, giving better information than the manufacturers provide, and should lead to a better understanding of the whole imaging process (Kenney, 2000).

Frey and Reilly recognized that "all of the chosen image quality parameters should be tied to well-documented standards to make it possible to take images safely into the future" (Frey, 2000) and that "for objective image quality measurements, software should be available which is designed to locate and evaluate specific targets and then report numbers or graphs describing key image quality parameters" (Frey, 1999) along with their tolerance limits (D'Amato, 2000). Simplification of the characterization process makes it more practical for future use by photographers in the museum environment.

The testing procedures defined in these standards can allow the photographer to determine whether the digital equipment can produce images that meet the needs for image quality. It is important that the digital image is a "replacement" of the original. Therefore, the digital data have to be captured and archived, along with technical metadata, in such a manner that the original can be reconstructed (Frey, 1996). The image quality testing procedures and accompanying test targets, if used correctly, can quickly inform the photographer of the level of image quality achievable by his imaging system before he even takes his first digital photograph of a piece of artwork. The outcome of these procedures are extensive quantitative descriptions of the image quality parameters, which characterize a camera used for the direct digital capture of cultural heritage.

The image quality parameters and metrics of a digital camera described in this standards review, which can be characterized, are as follows. Tone reproduction is the most important aspect of image quality. If the tone reproduction of an image is correct, users will generally accept it, even if the other attributes are not ideal (Frey, 2000). Tone reproduction is affected by three mutually dependent attributes: the opto-electronic conversion function (OECF), dynamic range, and flare. Resolution, or image detail, is another image quality parameter best described by a metric, the modulation transfer function (MTF), or spatial frequency response (SFR). Other image quality parameters include system spatial uniformity, color reproduction, and noise. The remainder of the standards described in this standards review do not directly describe image quality parameters, but are supplemental standards, and describe monitor viewing conditions, illuminant specifications, ISO speed determination, electronic imaging terminology, colorimetry and technical metadata. There are many metrics that, in combination, can be used to specify a desired level of image quality (D'Amato, 2000). Physical features of the original object can be characterized numerically and matched up with digital equivalencies (Kenney, 2000). Thus, if the original objects to be digitized are first characterized through measurements of their reflectances, colors, and levels of detail, it is then possible to select image quality test targets and testing procedures to ensure that these characteristics are faithfully captured in the images (D'Amato, 2000).

There are many standards provided by both national and international standards bodies for businesses, the government and society in order to allow for agreement on specifications, criteria and terminology. The major roles played by standards are that they raise levels of quality, safety, reliability, efficiency and interchangeability, as well as provide these benefits at an economical cost. Only a few of these standards bodies provide standards that apply directly to the digital capture of cultural heritage. The standards that will be described here are provided by the ISO (International Organization for Standardization), IEC (International Electrotechnical Commission), ANSI (American National Standards Institute), CIE (International Commission on Illumination) and NISO (National Information Standards Organization), each of which is related to each other in some way.

McDowell describes standards and specifications that apply to digital imaging as "nothing more than written agreements that describe how something should be done or the agreed upon characteristics of, or interfaces between, devices or software" (McDowell, 2002). The standards developed by the five standards bodies listed above were developed by a consensus. Participation in the decision making process to develop these standards is completely open, which means that the expertise that goes into the development of these standards is widespread (McDowell, 2002).[1]

As an example, the following is a brief summary of who develops standards and how they are developed in the ISO. There are similarities in most other standards bodies. The ISO has a Technical Committee, or TC, for each different area of research, which is ultimately responsible for developing the standards. A Sub-Committee (SC), a subgroup within a TC, a Working Group (WG), a subgroup within a SC or TC, or a Task Force (TF), a subgroup within a WG or SC, is formed to be directly involved in the creation process of a standard. Sometimes a Joint Working Group (JWG), which involves participants from multiple TCs, is needed for developing standards that overlap two or more areas of research. Figure 1 is a flowchart showing how a standard evolves from a New Work Item proposal into a Final Draft International Standard (FDIS).

[1] Some other specifications are developed solely within an industry trade group, such as the ICC (International Color Consortium), or within a single company or group of companies as "de facto" or private specifications, such as TIFF (Tag Image File Format).

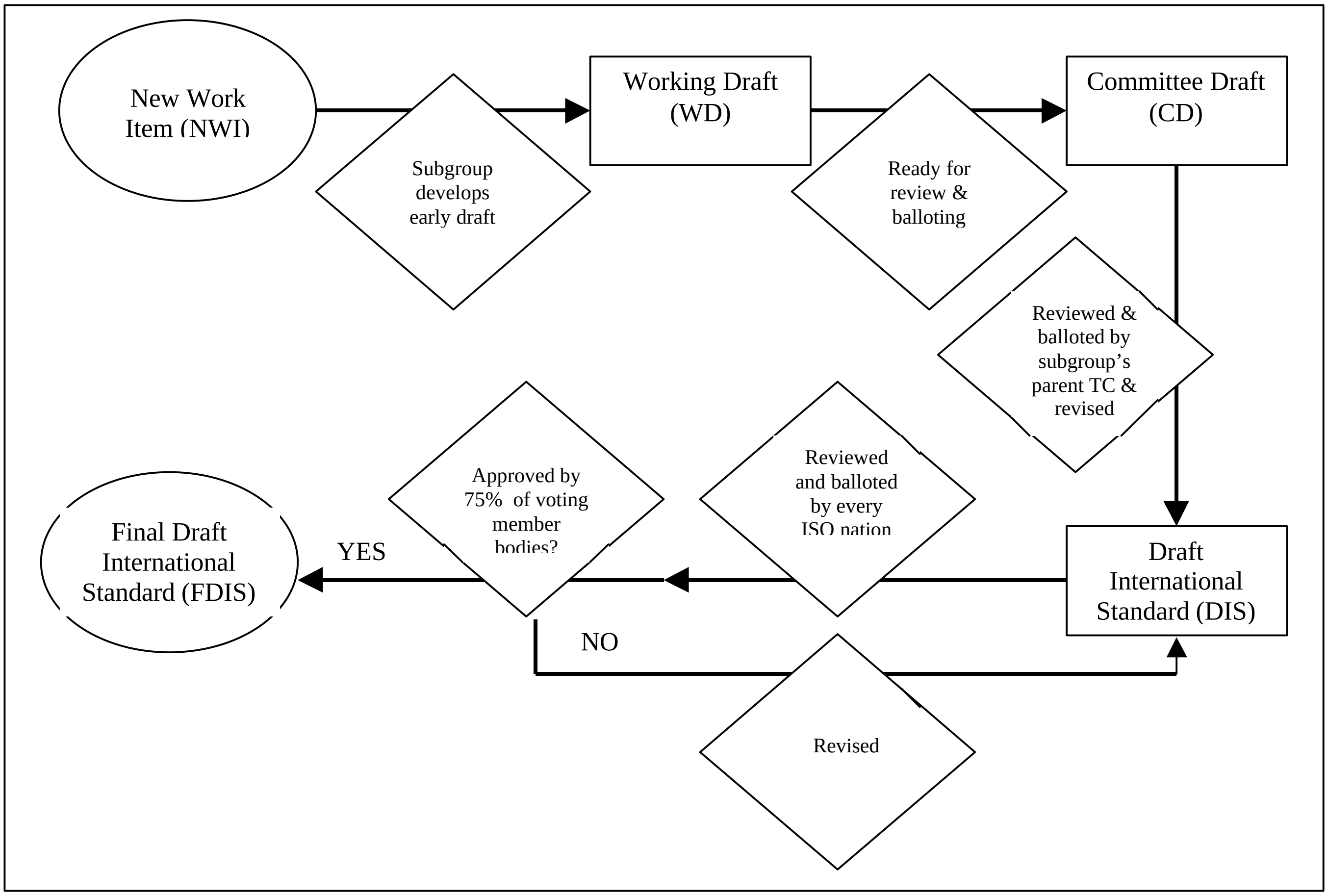


Figure 1: Flowchart of how a standard evolves in the ISO (McDowell, 2002).

Once a standard is published, it must be reviewed on a periodic basis to be sure that it is still applicable, but a revision can be produced at any time by the committee responsible for the standard (McDowell, 2002).

One clarification that should be noted about the standards language is that the words "shall" and "should", which are contained in some of the standards described below, have specific meanings. "Shall" means that you must do something in order to comply with the standard. "Should" means that it is really preferable to do something and you should try very hard to do it (Harold, 1999).

Not all of the standards described below were in their published FDIS form at the time in which this standards review was written. The form that each standard was in at the time that this was written is listed in Table I. The standards that are summarized[2] below, which were developed by the ISO, IEC and ANSI standards bodies pertain to the areas of photography, which includes the use of both digital still cameras and scanners, and graphic technology. The CIE publications[3] pertain to light sources and colorimetry, and the NISO standard pertains to the technical metadata of digital still images. The descriptions of the standards below will focus on information contained in the standards, which applies directly to target-based digital camera characterization testing procedures. Because the information in this standards review is in the form of a summarization, anyone wishing to use these standards should refer to the standard itself for detailed information. Table I lists the standards in the order that they will be reviewed here. Table II can be used as a reference for the image quality parameters discussed in each standard. A brief explanation about each standards body and a summary of each standard listed in Tables 1 and 2 will be given next.

[2] Most of the wording used in the summaries is taken directly from the standards themselves so that the meaning of the standard is not lost.

[3] Most CIE documents are technical publications or recommended practices. Only those labeled ISO/CIE are standards.

Title	**No.**	**Date**	**Organization**	**Form (in ISO terms)**	**Edition**	**TCs**	**Page #**
Viewing conditions - Graphic technology and photography	3664	02/01/2002	ISO	FDIS	2nd	ISO/TC 42 (Photography), ISO/TC 130 (Graphic Technology)	12
Photography - Illuminants for sensitometry - Specifications for daylight, incandescent tungsten and printer	7589	09/01/2000	ISO	FDIS	2nd	ISO/TC 42 (Photography)	14
Photography -- Electronic still-picture cameras -- Terminology	12231	06/15/1997	ISO	FDIS	1st	ISO/TC 42 (Photography)	16
Photography -- Electronic still-picture cameras -- Determination of ISO speed	12232	08/01/1998	ISO	FDIS	1st	ISO/TC 42 (Photography)	16
Photography -- Electronic still-picture cameras -- Resolution measurements	12233	09/01/2000	ISO	FDIS	1st	ISO/TC 42 (Photography)	19
Graphic Technology - Displays for color proofing - characteristics and viewing conditions	12646	05/30/2002	ISO	DIS	N/A	ISO/TC 130 (Graphic Technology)	25
Photography -- Electronic still-picture cameras -- Methods for measuring opto-electronic conversion functions (OECFs)	14524	12/15/1999	ISO	FDIS	1st	ISO/TC 42 (Photography)	29
Photography -- Electronic still-picture imaging -- Noise measurements	15739	05/01/2003	ISO	FDIS	1st	ISO/TC 42 (Photography)	32
Graphic technology and photography — Colour characterisation of digital still cameras (DSCs) — Part 1: Stimuli, metrology, and test procedures	17321-1	09/17/2003	ISO	WD	N/A	ISO/TC 42 (Photography), ISO/TC 130 (Graphic Technology)	35
Graphic technology and photography - Colour characterization of digital still cameras (DSCs) - Part 2: Methods for determining transforms from raw DSC to scene-referred data	17321-2	10/10/2003	ISO	WD	N/A	ISO/TC 42 (Photography), ISO/TC 130 (Graphic Technology)	39
Photography and Graphic Technology - extended color encodings for digital image storage, manipulation and interchange - Part 1: architecture and requirements	22028-1	08/30/2002	ISO	DIS	N/A	ISO/TC 42 (Photography), ISO/TC 130 (Graphic Technology)	41
Multimedia systems and equipment - Colour measurement and management - Part 2-1: Colour management - Default RGB colour space - sRGB	61966-2-1	10/1999 + 01/2003	IEC	FDIS	1st + Amd 1	IEC/TC 100 (Audio,video and multimedia systems and equipment)	44
Multimedia systems and equipment - Colour measurement and management - Part 8: Multimedia colour scanners	61966-8	02/2001	IEC	FDIS	1st	IEC/TC 100 (Audio,video and multimedia systems and equipment)	46
Multimedia systems and equipment - Colour measurement and management - Part 9: Digital cameras	61966-9	06/2000	IEC	FDIS	1st	IEC/TC 100 (Audio,video and multimedia systems and equipment)	50
Graphic Technology - Color reflection target for input scanner calibration	IT8.7/2	06/21/1993	ANSI	FDIS	1st	IT8 Subcommittee 4	54
Colorimetry	15.2	1986	CIE	N/A	2nd	CIE/TC 1.3 (Colorimetry)	57
A method for assessing the quality of daylight simulators for colorimetry	51	1981	CIE	N/A	1st	CIE/TC 1.3 (Colorimetry)	58
Data Dictionary - Technical Metadata for Digital Still Images	N/A	06/01/2002	NISO	DIS	N/A	N/A	61

Table I: List of standards that are summarized in this standards review.

				Image Quality Parameter							
Title	**No.**	**Organization**	**Page #**	**Spatial Uniformity**	**Tone Reproduction**	**Color Reproduction Accuracy**	**Noise**	**Dynamic Range**	**Image Flare**	**Resolution**	**Non-Image Quality**
Viewing conditions -- Graphic technology and photography	3664	ISO	12								***X***
Photography - Illuminants for sensitometry - Specifications for daylight, incandescent tungsten and printer	7589	ISO	14								***X***
Photography -- Electronic still-picture cameras -- Terminology	12231	ISO	16								***X***
Photography -- Electronic still-picture cameras -- Determination of ISO speed	12232	ISO	16								***X***
Photography -- Electronic still-picture cameras -- Resolution measurements	12233	ISO	19							***X***	
Graphic Technology - Displays for color proofing - characteristics and viewing conditions	12646	ISO	25								***X***
Photography -- Electronic still-picture cameras -- Methods for measuring opto-electronic conversion functions (OECFs)	14524	ISO	29		***X***						
Photography -- Electronic still-picture imaging -- Noise measurements	15739	ISO	32				***X***	***X***			
Graphic technology and photography — Colour characterisation of digital still cameras (DSCs) — Part 1: Stimuli, metrology, and test procedures	17321-1	ISO	35			***X***					
Graphic technology and photography - Colour characterization of digital still cameras (DSCs) - Part 2: Methods for determining transforms from raw DSC to scene-referred data	17321-2	ISO	39			***X***					

				Image Quality Parameter							
Title	No.	Organization	Page #	Spatial Uniformity	Tone Reproduction	Color Reproduction Accuracy	Noise	Dynamic Range	Image Flare	Resolution	Non-Image Quality
Photography and Graphic Technology - extended color encodings for digital image storage, manipulation and interchange - Part 1: architecture and requirements	22028-1	ISO	41			*X*					
Multimedia systems and equipment - Colour measurement and management - Part 2-1: Colour management - Default RGB colour space - sRGB	61966-2-1	IEC	44			*X*					
Multimedia systems and equipment - Colour measurement and management - Part 8: Multimedia colour scanners	61966-8	IEC	46	*X*	*X*	*X*			*X*		
Multimedia systems and equipment - Colour measurement and management - Part 9: Digital cameras	61966-9	IEC	50	*X*	*X*	*X*					
Graphic Technology - Color reflection target for input scanner calibration	IT8.7/2	ANSI	54			*X*					
Colorimetry	15.2	CIE	57								*X*
A method for assessing the quality of daylight simulators for colorimetry	51	CIE	58								*X*
Data Dictionary - Technical Metadata for Digital Still Images	N/A	NISO	61								*X*

Table II: A reference for the image quality parameters discussed in each standard.

3. ISO

The ISO is a non-governmental international standards body made up of a network of national standards institutes from 147 countries working in partnership with international organizations, governments, industry, businesses, and consumer representatives. The ISO collaborates closely with the IEC and is responsible for all standards areas not specifically assigned to the IEC.

ISO 3664, Viewing conditions – Graphic technology and photography

This standard specifies illumination and viewing conditions for reflective media, such as prints, transmissive media, such as transparencies, and images displayed on a color monitor, which are not viewed in comparison to any form of hardcopy simultaneously. The viewing conditions described in the standard for the third case are what are pertinent to the topic of this standards review. When a monitor viewing condition is standardized and properly implemented by various people in a production chain, then errors and misunderstandings about color reproduction and processing will be minimized. The standard does not, however, dismiss the fact that the best viewing condition for the visual assessment of color is that in which the product will be finally seen, but it stresses that this viewing condition must be well specified and agreed upon by everyone in the production chain for it to be effective.

As mentioned above, the specifications provided by the standard are only relevant to images viewed successively, not simultaneously, with a hardcopy. The standard recommends the unpublished standard *ISO 12646, Graphic Technology – Displays for color proofing – Characteristics and viewing conditions* for the direct comparison of softcopy and hardcopy. That standard is summarized on page 25.

The color monitor viewing conditions specified in the standard are as follows. The chromaticity of the white displayed on the monitor should be approximately D_{65}. The standard refers to *CIE Publication No. 51, A method for assessing the quality of daylight simulators for colorimetry*, which is summarized on page 58, for evaluating whether a particular light source is considered to be a D_{65} illuminant. The white point of the monitor should have u'_{10}, v'_{10} coordinates within the radius of 0.025 of $u'_{10} = 0.1979$ and $v'_{10} = 0.4695$ in the CIE 1976 Uniform Chromaticity Scale (UCS) Diagram. The luminance level of the white displayed on the monitor shall be greater than 75 cd/m^2 and should be greater than 100 cd/m^2. The level of ambient illumination, when measured at the face of the monitor or in any plane between the monitor and the observer with a cosine corrected photometer and with the monitor switched off, shall be less than, or equal to, 64 lux and should be less than, or equal to, 32 lux. The correlated color temperature of the ambient illumination shall be less than, or equal to, that of the monitor white point. If the ambient illumination approaches the maximum illumination levels above, then the chromaticity of the ambient illumination should be approximately the same as the white point of the monitor, so that chromatic adaptation complications are minimized. The area immediately surrounding the displayed image and its border shall be neutral, preferably dark gray or black to minimize flare, and of approximately the same chromaticity of the white point of the monitor. The luminance of the border of the image should be 20% of the white point luminance, or less, and preferably 3% of the white point luminance, or less. There should be no strongly colored areas, including clothing, directly in the field of view of the monitor or which may cause reflections in the monitor screen. Ideally, the walls, floors, and furniture in the field of view should be gray and free of any objects, which may affect the vision of the viewer. All sources of glare, such as from unshielded lamps or windows, which are directly in the field of view or are causing reflections from the surface of the monitor, should be avoided.

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

This standard specifies the spectral characteristics of three corresponding illuminants for film sensitometry (daylight, studio tungsten, and photoflood) and one for black-and-white paper sensitometry (incandescent tungsten). It also describes methods for evaluating the acceptability of illuminants for sensitometry and specifies tolerances. Since the standard is referenced in some of the standards summarized below to determine whether an illuminant is an acceptable match to a defined ISO illuminant, it is an important standard to include in this review. The relative spectral power distributions of the four ISO sensitometric illuminants described in the standard were obtained by operating a lamp at a specified condition and modulating the flux with selectively absorbing filters of suitable spectral transmittance, and are presented in tables at 10nm intervals.

The "ISO sensitometric daylight illuminant" spectral power distribution data, listed in the standard from 350nm to 690nm, correspond to a correlated color temperature of 5500K designated as D_{55} and was obtained from *CIE Publication No. 15.2, Colorimetry*, summarized on page 57. This illuminant is defined as the product of the spectral power distribution of photographic daylight (D_{55}) and the spectral transmittance of the ISO standard camera lens. The "ISO sensitometric studio tungsten illuminant" spectral power distribution data, also listed in the standard from 350nm to 690nm, correspond to a correlated color temperature of about 3050K. It is defined in the same way as the daylight illuminant in the standard. The "ISO sensitometric photoflood illuminant" is similarly defined, but with a correlated color temperature of 3400K. Details about the "ISO sensitometric printer illuminant" are not necessary to mention here, but are explained in the standard.

The spectral distribution index (ISO/SDI) is a three-number designation which describes how well a test illuminant matches a specified spectral power distribution in terms of the total photographic responses of the three component emulsions of average color films. Weighted spectral sensitivity values, which were derived from average color film relative sensitivities for each film layer produced by several manufacturers worldwide, used to evaluate candidate illuminants for acceptability are listed in the standard for the ISO daylight, studio tungsten, and photoflood illuminants described above. They are weighted so that the aim relative spectral power values for the ISO illuminant will yield an ISO/SDI of 0/0/0.

The process of calculating an ISO/SDI designation is as follows. First, the relative spectral power values of a candidate illuminant are determined at 10nm intervals. These values are multiplied by each of the appropriate blue, green and red weighted spectral sensitivity values. The total responses are obtained by summing each result. Then, the logarithms to the base 10 of the total response values are determined to two decimal places. The smallest element of the three-number designation is subtracted from all three $\log_{10}$ values, making the smallest element equal to zero. Finally, all three designations are multiplied by 100. The resulting numbers are the ISO/SDI for the candidate illuminant. An example of this calculation is given in an annex in the standard. To meet the requirements of the standard, the red index shall not differ from the green index by more than ±3, and the blue index shall not differ from the green index by more than ±4. A trilinear diagram is used in the standard to show these tolerances. Examples of actual lamp-filter combinations that meet these requirements are listed in an annex in the standard.

ISO 12231, Photography – Electronic still-picture cameras – Terminology

The purpose of this standard is to standardize the use and meaning of terms associated with electronic still-picture cameras. Even though electronic photography concepts are drawn from traditional photography, electronics, video and information technology, some of these concepts need to be redefined to apply to electronic photography. The source of most of the terms listed in the standard are the standards *ISO 12232, Photography – Electronic still-picture cameras – Determination of ISO speed, ISO 12233, Photography – Electronic still-picture cameras – Resolution measurements,* and *ISO 12234, Photography – Electronic still-picture cameras – Removable memory*, which is the only standard, out of the three, that will not be summarized in this standards review because it is not considered directly relevant to its topic.

ISO 12232, Photography – Electronic still-picture cameras – Determination of ISO speed

This standard specifies a method for assigning exposure index values, ISO speed ratings, and ISO speed latitude ratings to electronic still-picture cameras, so that they relate, as much as possible, to current traditional photography standards. ISO speed is defined in the standard as the numerical value calculated from the exposure provided at the focal plane of an electronic camera to produce specified camera output signal characteristics using the methods described in the standard. It should correlate with the highest exposure index value that provides peak image quality for normal scenes. The exposure index is defined in the standard as the numerical value that is inversely proportional to the exposure provided to an image sensor to obtain an image.

Standardization of the ISO speed rating is useful for electronic camera users and manufacturers, because it assists them in obtaining proper exposures and in determining the low light capability of electronic still cameras. The exposure time, lens aperture, lens transmittance, level and color temperature of the scene illumination, and scene reflectance determine the camera exposure. When an image from an electronic still-picture camera is captured using an insufficient exposure, proper tone reproduction can generally be maintained by increasing the electronic gain, but the image will contain an unacceptable amount of noise. As the exposure is increased, the gain can be decreased, and therefore the image noise can normally be reduced to an acceptable level. If the exposure is increased excessively, the resulting signal in bright areas of the image may exceed the maximum signal level capacity of the image sensor of camera signal processing. Cameras with variable gain, and digital processing after the data has been captured, allow desired tone reproduction to be achieved over a range of camera exposures and speed ranges. The ISO speed latitude is defined as this range of speed ratings.

The standard explains how to calculate the following metrics. Exposure index, saturation-based speed, and noise-based speed can all be calculated using either the focal plane exposure measurement or the scene luminance measurement. The two ISO speed ratings above should indicate, when reported, whether daylight or tungsten illumination was used. The standard references the ISO standard *7589, Photography – Illuminants for sensitometry – Specifications for daylight and incandescent tungsten*, which was described on page 14, for the determination of whether an illuminant is an acceptable match to either of these two illuminants. The standard also specifies that for the determination of ISO speed, the temperature during the acquisition of the test data shall be 23°C ± 2°C, the relative humidity should be 50% ± 20%, the camera white balance should be adjusted to provide proper white balance for the illumination light source, an IR blocking filter shall be used, if required, and the photosite integration time, which is defined as the total time period during which the photosites of an image sensor are able to integrate the light from the scene to form an image, should not be longer than 1/30s.

The maximum exposure level is the exposure level where typical picture highlights will be clipped as a result of saturating the image sensor capacity or reaching the maximum signal level for camera signal processing. The minimum exposure level depends on the amount of noise that can be tolerated in the image. The saturation-based speed values describe the former case, and the noise-based speed values describe the latter case. The camera ISO speed is preferably determined using the noise-based speed value, $S_{noise40}$, method. The saturation-based speed value is preferably used to indicate the camera's overexposure speed latitude, and a second noise-based speed value, $S_{noise10}$, is preferably used to indicate the camera's underexposure speed latitude. The visibility of noise to human observers depends on the magnitude of the noise, the apparent tone of the area containing the noise, and the spatial frequency of the noise. The noise visibility is different for the luminance channel and the color channels, so the standard accounts for these factors in measuring the noise-based speed and speed latitude values.

The saturation-based speed rating is appropriate to use as the ISO speed of the electronic camera in photographic situations where the scene illumination level can be controlled, because the photographer wants a camera exposure index setting that provides the best possible image quality. Using the saturation-based speed rating, the photographer can set the camera exposure so that the image highlights are just below the maximum possible camera signal value.

The noise-based speed rating is most appropriately used as the ISO speed of the electronic camera in photographic applications where it is desirable to have the highest exposure index, or lowest exposure, possible in order to maximize the depth of field, minimize the exposure time, and offer the maximum acceptable speed latitude for exposure of image highlights. Two different noise-based speeds are determined, one that provides the “first excellent” image, $S_{noise40}$, and a second that provides the “first acceptable” image, $S_{noise10}$. $S_{noise40}$ and $S_{noise10}$ have signal-to-noise, S/N, ratios of 40 and 10, respectively. If the electronic still-picture camera is too noisy to meet the S/N = 40 criterion, then the noise-based speed values shall not be reported and the saturation-based speed value shall be reported as the ISO speed of the camera. If the electronic still-picture camera includes any form of lossy compression, it shall be disabled, otherwise the noise-based speed values cannot be properly determined, and shall not be reported.

At the end of the standard, the method of reporting the ISO speed values is explained and a table is given for the value that should be reported when the saturation-based or noise-based speed ratings are between certain ranges of values. The standard also mentions that for electronic still-picture cameras that form a color image using a monochrome image sensor and a color-filter wheel, the ISO speed and speed latitude of each color should be measured and reported separately. In an informative appendix, the standard gives an equation for converting a $S_{noise10}$ value to a minimum scene illumination level for consumer electronic still-picture cameras that use a minimum scene illumination level rating to define their sensitivity.

ISO 12233, Photography – Electronic still-picture cameras – Resolution measurements

This standard defines terminology, test charts and test methods for performing resolution measurements for analog and digital electronic still-picture cameras. The standard summary will focus on the latter type of camera. The ability to resolve detail is determined by the performance of the camera lens, the number of addressable photoelements in the optical imaging device, and the electrical circuits in the camera, which may include image compression and gamma correction functions. Different metrics result from different measurement methods for quantifying the resolution of an imaging system. Resolution metrics include resolving power, limiting resolution at some specified contrast, spatial frequency response, or SFR, which is the measured amplitude response of an imaging system as a function of relative spatial frequency, optical transfer function, or OTF, which is the two-dimensional Fourier transform of the imaging system's point spread function, a normalized spatial signal distribution in the linearized output of an imaging system resulting from imaging a theoretical infinitely small point source, and modulation transfer function, or MTF, which is the modulus of the OTF.

The first step in measuring resolution is to capture an image of a suitable test chart with the electronic camera being tested. This chart should include patterns with sufficiently fine detail, such as edges, lines, square waves, or sine wave patterns. A resolution test chart is defined in the standard. The SFR measurement method described in the standard uses a computer algorithm, which is available in both the C programming language and in an Adobe Photoshop® plug-in, to analyze digital data from the electronic still-picture camera. Digitized image values near slanted vertical and horizontal black to white edges are digitized and used to compute the SFR values. Using a slanted edge for the SFR measurement allow the edge gradient to be measured at many phases relative to the image sensor photoelements, in order to eliminate the effects of aliasing, which is defined in the standard as output image artifacts that occur in a sampled imaging system for input images having significant energy at frequencies higher than the

Nyquist frequency, or the spatial frequency equal to ½ times the inverse of the sampling period, of the system.

The resolution test chart defined in the standard is shown in Figure 2.

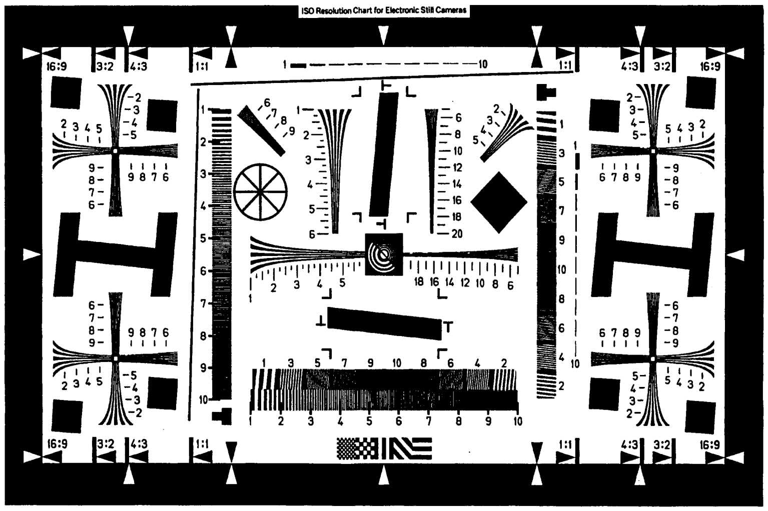


Figure 2: ISO Resolution Chart for electronic still cameras.

The test patterns in this test chart can be separated and rearranged and the framing and reproduction scale of the patterns can also be varied. This test chart is designed for cameras having a limiting resolution of less than 2000 line widths per picture height (LW/PH), but it can be used for electronic cameras having a limiting resolution greater than 2000 LW/PH by adjusting the camera to target distance, or focal length of the camera lens, so that the test chart active area fills only a fraction of the vertical image height of the camera and then multiplying the test chart features by this fraction to obtain correct values. The test patterns on this test chart are bi-tonal patterns which are spectrally neutral. The characteristics of the test chart such as the material, size, test-pattern modulation, units, features, and the positional tolerance of any test chart feature are all specified in the standard. A description of the purpose of each test pattern on the chart is also given in the standard.

The conditions under which the test chart should be digitally photographed are as follows. The luminance of the test chart shall be sufficient to provide an acceptable camera output signal level. It shall be uniformly illuminated and the illumination sources should be baffled to prevent direct illumination of the camera lens by the illumination sources. The area surrounding the chart should be of low reflectance, to minimize image flare, and the chart should be shielded from any reflected light. The approximate distance between the camera and the test chart should be reported along with the measurement results. The camera focus should be determined by capturing the chart at a variety of focus settings and selecting the focus setting that provides the highest average modulation level at a spatial frequency of about ¼ the camera Nyquist frequency. The camera focus can alternatively be determined so that the zone plate in the center of the chart exhibits the maximum aliasing possible. The camera exposure should be adjusted so that a near maximum signal level from the white test target areas is achieved. This exposure setting shall not have signal clipping in either the white or black areas of the test chart. All camera-setting values shall be reported along with the measurements. Multiple SFR measurements may be reported for different camera settings. The camera white balance should be adjusted so that proper white balance is provided for the illumination light source. The resolution measurements should be performed on the camera luminance channel only. Also, the signal shall be linearized before the data analysis is performed, by applying the inverse of the camera opto-electronic conversion function, or OECF, because a non-linear response will affect the SFR values, since they are defined on a linearized output signal.

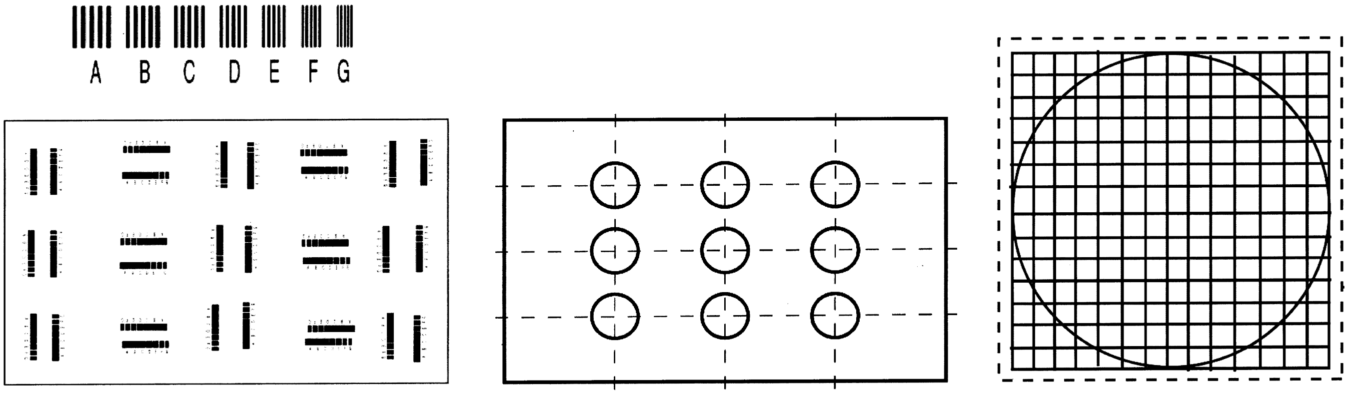
The test chart in Figure 2 can be used to determine the visual resolution, limiting resolution, spatial frequency response, and aliasing ratio. The visual resolution is the lowest value of the hyperbolic wedge test pattern, in LW/PH, where the individual black and white lines can no longer be distinguished, or are reproduced at a spatial frequency lower than the spatial frequency of the corresponding area of the test chart, which results from aliasing. In order to determine the visual resolution, the image of the test chart is reproduced on a monitor or hard-copy print, and the visual resolution is subjectively judged. The visual resolution value shall not exceed the Nyquist frequency limit. The limiting resolution is the value, in LW/PH, of that portion of the black and white vertical or horizontal square wave sweep where the resolution response (average depth of modulation value) equals 5% of the reference response, which is defined as the difference between the signal values from the slanted black bar and the white region just below the bar. If necessary, multiple images should be averaged to reduce the influence of noise in the determination of the 5% level.

The spatial frequency response, or SFR, of an electronic still-picture camera is measured by analyzing the electronic camera data near a slanted black to white edge. The test chart shown in Figure 2 allows the SFR to be measured horizontally, vertically, and diagonally in the center, corners, and sides of the captured image. The standard provides a workflow diagram and the C-code of an algorithm used to compute SFR. A vertically oriented black to white slanted edge is used to measure the horizontal SFR and a horizontally oriented slanted edge is used to measure the vertical SFR in the algorithm. The aliasing level is measured using the horizontal and vertical 100 LW/PH to 1000 LW/PH slanted burst patterns in the test chart shown in Figure 2. When aliasing does not occur, the signal level from each black bar, or each white bar, should be identical for each bar in the burst. When aliasing does occur, the signal responses of the camera to the white bars of a particular burst may not be identical, but instead, the response may have a maximum signal value for some white bars, and a minimum signal value for other white bars. The aliasing ratio is the ratio of the *maximum minus the minimum response* for the white bars within a burst to the *average white-bar signal minus the average black-bar signal* within the burst for a particular spatial frequency burst.

The visual resolution values shall be reported as spatial frequency values, in LW/PH, for the horizontal, vertical, and diagonal directions. The limiting resolution values shall be reported the same way, but only for the horizontal and diagonal directions. The SFR values reported shall be the average of four SFR measurements of a black to white edge and four SFR measurements of a white to black edge taken in the middle of the slanted bars. The average SFR results should be reported separately for each direction measured using a graph plotting the modulation level versus spatial frequency where the modulation has a value of 1 at 0 spatial frequency, or by listing the SFR values versus spatial frequency. The spatial frequency axis should range from 0 to the sensor sampling frequency, where the camera Nyquist frequency is labeled and the values between ½ and 1 times the sensor sampling frequency is marked to indicate that these spatial frequencies lead to aliasing. This axis should be labeled with three units: frequency relative to the sensor sampling frequency, LW/PH, and cycles/mm on the sensor, or with equations that represent the relationships between these units. The aliasing ratio values should be reported in a list that indicates the frequency in LW/PH, from 100 LW/PH up to the camera Nyquist frequency, and the aliasing ratios in both the horizontal and vertical directions for each frequency. An informative annex at the end of the standard lists a few relationships between resolution metrics for sine and square waves.

ISO 12646, Graphic Technology – Displays for colour proofing – Characteristics and viewing conditions

This unpublished standard specifies requirements for uniformity, size, resolution, convergence, refresh rate, luminance levels and viewing conditions for a color display used to simulate a hard copy proofing system. Because the standard was developed by the Graphic Technology technical committee, it is geared toward matching color images displayed on color monitors to the images produced when the same digital file is rendered by proofing and printing systems. Even though the images obtained from the digital camera, which will be displayed on the monitor, may not be visually matched with a proof or printed reproduction, they will, however, be visually matched with the original, or source. Therefore, the information contained in the standard will be useful in defining viewing conditions for this purpose. This summarization will focus on information pertaining to this particular application. The standard is primarily based on CRT display technology, but its recommendations might be appropriate for newer display technologies. The requirements and test methods of the display are described in the paragraphs that follow. Figures 3 a, b, and c show the test images used in the test methods described below.



a b c

Figure 3 a, b, c: a) Resolution target (above) and its layout (below), b) Positions for measurement of uniformity, c) Grid pattern for assessment of convergence and geometric accuracy.

The display resolution shall be sufficient to display an image of 1280 x 1024 pixels without interpolation. The test image in Figure 3a, with lines and spaces that are equal in width for each field and that range from 0.5mm to 0.2mm in intervals of 0.05mm, shall be used. When viewed normally, and at a typical viewing distance (approximately 0.5m), the lines labeled D shall be clearly distinguishable and those labeled F should be clearly distinguishable, for all images within the central region (defined as that within half the linear diagonal distance) of the display. Any images outside this region may have a resolution poorer by 0.05mm.

The display shall be capable of displaying an image having a diagonal measurement of at least 17” and a height of at least 8.5”. The CRT display shall have a refresh rate of at least 80Hz, noninterlaced.

The display should be visually uniform when displaying flat white, gray and black images that each fills the screen. The white image shall consist of the maximum value of the red, green, and blue channels (255 for an 8-bit display). The neutrality and luminance level of the gray and black images is not critical. However, the gray image should consist of approximately half of the maximum value in each channel (127 for an 8-bit display), and the black image should consist of approximately a quarter of the maximum value in each channel (63 for an 8-bit display). For each level, 9 points of the image area of the screen shall be measured, as shown in Figure 3b, using a photometer or radiometer. All luminance values should be within 5% of the luminance of the center and shall be within 10% of it, however, there should not be areas of significant visual non-uniformity between these areas.

When the grid pattern, shown in Figure 3c is displayed, geometric accuracy should be visually assessed by ensuring that the boundary pattern is all present, and that there is negligible distortion of the circle. The lengths of the lines should also be measured. The length of adjacent lines of the grid pattern shall be within 2mm of each other and no line length shall deviate by more than 2.5mm from the mean length. Convergence, which is the ability of the three electron beams to come together at a single spot on the surface of the CRT, shall be evaluated using the grid pattern in Figure 3c, by visually assessing whether all lines are wholly free of color fringing within the central region. A small amount of fringing may be accepted outside this area, but is not recommended.

The ambient illumination conditions defined in the standard are more restrictive than those defined in ISO standard *3664, Viewing conditions – Graphic Technology and photography*. An additional constraint beyond ISO 3664 is added to ensure that any reflected glare from the front surface of the display does not significantly reduce the perceived contrast. The requirements set forth in the standard are as follows. The level of illumination shall be less than 32 lux. The surround shall be no more than 10% of the maximum luminance of the screen. The color temperature of the ambient illumination shall approximate D_{50}. The level of illumination when viewing a black screen (R=G=B=0) shall be less than 5% of that obtained when viewing a white screen (R=G=B=255) when measured at the plane of the observer.

The white and black images, defined above, should be measured using a spectroradiometer or shall be measured using a tristimulus colorimeter, if no spectroradiometer is available, in contact with the display, in order to determine the chromaticity and luminance of the white and black points of the display. At the center of the white image, the chromaticity of the display should be set to that of D_{50} (u'=0.2092, v'=0.4881). The chromaticity obtained shall be within a circle of radius 0.005 (in u', v') from this point. This chromaticity shall be measured at the other points shown in Figure 3b and must be within 0.01 of the chromaticity of D_{50}. The luminance level should be as high as practical, but shall be at least 80cd/m^2 and should be at least 120cd/m^2. The black point shall have a luminance that is less than 1% of the maximum luminance. The black point chromaticity shall be measured at a luminance level of 10% of the maximum luminance and shall be within a circle of radius 0.03 of the chromaticity of the white point. The gain of the individual channel amplifiers shall be adjusted to achieve these white and black point settings. After they are set, the gain, offset, and gamma shall be determined from the chromaticities measured for at least 10 neutral colors (R=G=B) at levels of luminance spanning white to full black, which are approximately equally spaced in lightness (L*). The gamma of the CRT display should be in the range 2 to 2.4 for each channel.

Even when the display meets the requirements, described above, of the standard, it does not guarantee that a displayed image will match the color of the hardcopy. To achieve a color match, it is necessary to provide a color transformation such that the color data format, in which the image is encoded, can be transformed into that required by the color display. An annex in the standard makes some recommendations for achieving an acceptable color transformation. The annex also states that in order to retain the validity of a characterization of the monitor, it should be calibrated at regular intervals by measuring the white point and opto-electronic transfer function to ensure that they are consistent with those obtained at the time of the characterization.

ISO 14524, Photography – Electronic still-picture cameras – Methods for measuring opto-electronic conversion functions (OECFs)

This standard describes methods for measuring the functional relationship between the focal-plane log exposures or scene luminances, and the digital output levels of a digital camera. It accounts for the variables caused by the flexibility of digital cameras in determining this functional relationship. The OECF shows the relation between a physical input and digital code values assigned to this physical input. Digital values are assigned arbitrarily and do not have physical meaning or units. The standard applies to both monochrome and color electronic still-picture cameras.

Test methods for measuring both camera OECFs and focal plane OECFs are described in the standard. Camera OECFs have scene log luminances in units of $\log_{10}$ candela per square meter as input and include the effects of the camera lens and associated flare. Focal plane OECFs do not include these effects because they are scene independent and have focal plane log exposures in units of $\log_{10}$ lux seconds as input. The camera OECF test charts are designed to simulate the image formation effects produced by a scene with a specific luminance ratio and average distribution of luminances. For scenes, which are significantly different from average, the camera OECF measurements may be quite different. The main advantage of focal plane OECFs over camera OECFs is that they are scene independent. The camera OECF measurement method, on the other hand, allows for a one-step determination of the camera system characteristics for the scene simulated by the test chart being used, and focal plane values to be estimated from the camera OECF values for the midtone and highlight regions of most images if they are covered by the test chart being used.

The standard describes two methods for the focal plane OECF measurement and one for the camera OECF measurement. The first, more accurate, focal plane OECF measurement method involves exposing the electronic still-picture camera sensor directly to specific quantities of uniform illumination with the camera lens removed. The second method is used when the camera does not have a removable lens. This method involves using a uniformly emissive, approximately Lambertian reflective or illuminating target, which is imaged by the camera lens on the sensor. The remainder of this standard's summary will focus on the camera OECF measurement method, since it is a target-based method.

The camera OECF measurement method requires the camera lens to be on the camera. The chart illumination source should be equivalent to either the daylight or tungsten ISO standard source defined in *7589, Photography – Illuminants for sensitometry – Specifications for daylight and incandescent tungsten*, which was described on page 14. The chart or target, and the camera lens should be shielded from external illumination sources and reflective surfaces. The shielding materials and the wall behind the chart or target shall be black. The reflective chart or target shall be illuminated at a 45° angle from both sides of the normal. The standard specifies that the ambient temperature and relative humidity shall be 23°C ± 2°C and 50% ± 20%, respectively, when the test chart is imaged. The white balance shall be set to provide neutral digital output levels for the camera OECF test-chart background and the type of white balance (fixed, variable, automatic) shall be specified. An infrared-blocking filter shall be placed in front of the camera lens if required. Also, the camera lens shall be focused so that the test chart image appears sharp.

The standard camera OECF test chart is shown in Figure 4. The specifications for this chart are described in an annex in the standard.

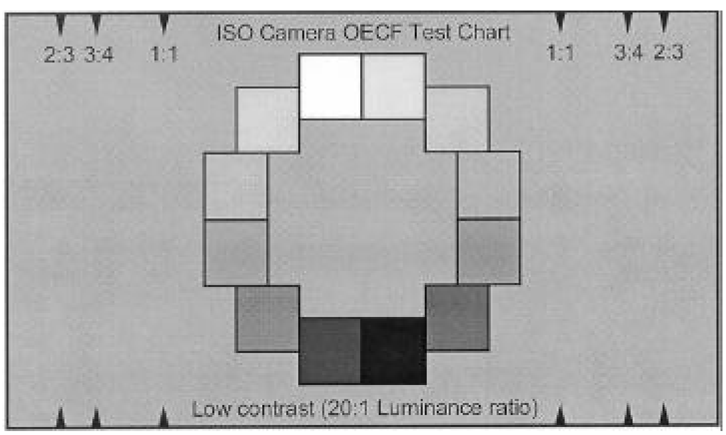


Figure 4: ISO Camera OECF Test Chart.

The chart luminances should be measured using a telescopic photometer placed where the camera would be. When each patch is measured, they should be masked with black in order to prevent flare from affecting the measurements. Alternatively, if a telescopic photometer is not available, the chart luminances may be calculated from the chart densities and illuminance. The chart shall be imaged a minimum of nine times each exposure level, where a trial shall consist of separate exposures for the camera being measured. The mean digital output level of each patch should be determined using a centrally located 64 by 64 pixel area at the same relative position of each image. The final digital output level data is calculated as the mean of the nine mean digital output levels. The results of the OECF measurement shall be presented in tabular and/or graphical form, which are described in more detail in the standard. In addition, all log luminances shall be to base 10.

In an informative annex in the standard, the relevancy of ISO/SDI calculations, described in ISO standard *7589*, to the qualification of illumination sources for digital still cameras is discussed, since this designation was based on the total photographic responses of the three component emulsions of average color films.

ISO 15739, Photography – Electronic still-picture imaging – Noise measurements

The noise performance of a digital image sensor may vary significantly with exposure time and operating temperature. The magnitude of the noise, the apparent tone of the area containing the noise, and the spatial frequency of the noise all affect the visibility of the noise to human observers. The noise visibility is different for the luminance channel and the color channels. The amount of noise in an output image depends on the noise present in the stored image data and the contrast amplification or gain applied to the data during image processing of the image. The standard accounts for these factors in the noise measurements and the reporting of them. The standard specifies the methods for measuring and reporting the noise versus signal level and dynamic range of electronic still-picture cameras. It can be used to characterize the noise in both monochromatic and color electronic still-picture cameras.

The noise measurement procedures described in the standard shall be used to determine the total signal-to-noise ratio (S/N), the fixed pattern signal-to-noise ratio, the temporal signal-to-noise ratio, and the dynamic range of the camera. In addition, total noise can be weighted to match a known expression for the human visual response. There are three types of noise measurement procedures described in the standard. One is a uniform field noise measurement method with the camera lens removed, the second is a uniform field noise measurement method with the camera lens attached to the camera, and the third is a test chart noise measurement method. This third method will be focused on for the remainder of this standard's summary.

The general test conditions for this method are as follows. The noise measurements shall indicate whether a source conforming to the daylight or tungsten illuminant, as they are defined in ISO standard *7589, Photography – Illuminants for sensitometry – Specifications for daylight and incandescent tungsten,* which was described on page 14, was used. For daylight illumination, the spectral characteristics of the illuminant shall be equivalent to CIE illuminant D55. For tungsten illumination, the spectral characteristics of the illuminant shall be equivalent to the product of the average spectral power distribution of experimentally measured sources having a color temperature of approximately 3050K. The reflective chart or target shall be illuminated at a 45° angle from both sides of the normal. The standard specifies that the ambient temperature and relative humidity shall be 23°C ± 2°C and 50% ± 20%, respectively, when the test chart is imaged. The camera white balance shall be adjusted so that equal RGB signal levels are achieved for the illumination light source. Also, an infrared-blocking filter shall be used, if required. The photosite integration time should not be longer than 1/30s. During the noise measurements, any compression shall be disabled.

Equations are given for determining visually weighted luminance from the individual red, green and blue channel outputs for color cameras using a single exposure process, and for determining the visually weighted standard deviation of the test chart patches for color cameras with luminance and color-difference outputs, which are each used when visually weighted camera noise is calculated.

The standard camera noise test chart is shown in Figure 5. The specifications for this chart are described in an annex in the standard.

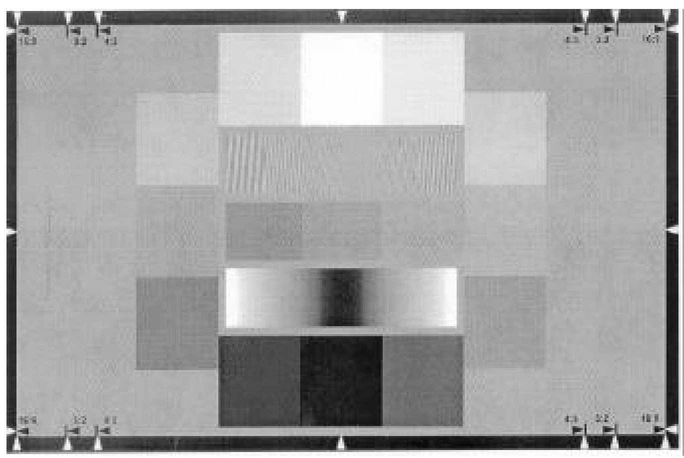


Figure 5: ISO Camera Noise Test Chart.

The major components of the test chart noise measurement procedure is as follows. The camera OECF shall first be measured according to the ISO standard *14524, Photography – Electronic still-picture cameras – Methods for measuring opto-electronic conversion functions (OECFs),* which is described on page 29. The light source shall be fixed level and shall be adjusted so that the lightest patch of the test chart gives the maximum unclipped level from the camera. A neutral density filter can be used over the camera lens to achieve this result. The camera lens may be shielded from any stray illumination. Non-uniformity in the test chart density patches shall be less than 1/10th of the expected camera noise level. The test chart shall be correctly focused by the camera. The whole apparatus shall be securely mounted to reduce movement between exposures less than ¼ of a pixel.

A minimum of eight images shall be captured of the test chart. An Adobe Photoshop® plug-in is available that will perform the following determinations and calculations, along with visual noise measurements. The mean digital code value and rms noise level shall be determined from a centrally located area of not less than 64 by 64 for each patch in each image. The first derivative of the OECF is calculated in order to produce the incremental gain function, which is defined in the standard as the change in digital code value divided by the change in luminance or exposure as a function of light level. It is used in each of the equations, which are used to determine the total, fixed pattern, and temporal S/N ratios, and the ISO dynamic range. The three S/N ratio equations use the data from the central three patches of the chart shown in Figure 5. The ISO digital still camera dynamic range is the ratio of the maximum unclipped luminance level to the minimum luminance level that can be reproduced with a temporal S/N ratio of at least 1. The camera dynamic range is obtained by measuring the temporal S/N ratio using the darkest patch in the chart shown in Figure 5. More details about these calculations can be found in the standard. In addition, an informative annex in the standard explains how to determine edge noise using the square wave part of the chart in Figure 5. This edge noise is termed the ISO standard camera high frequency S/N ratio.

ISO 17321-1, Graphic Technology and photography – Colour characterization of digital still cameras (DSCs) – Part 1: Stimuli, metrology, and test procedures

The spectral responses of the color analysis channels of digital still cameras do not, in general, match those of a typical human observer. Nor do the responses of different digital still cameras ordinarily match each other. In characterizing these cameras, it is therefore necessary to take account of their spectral sensitivities, illumination, and encoding color space. Part 1 of this unpublished standard, which is summarized here, will define stimuli (spectral illumination or a color target), metrology and photographic test procedures for acquiring digital still camera characterization data. This characterization data will be expressed as raw (sensor-referred) data. Some operations, such as color pixel reconstruction, flare removal, and white balancing, may be performed without disqualifying the data as being raw. Two alternative methods are described in the standard for obtaining this raw digital still camera data. A spectral method will use narrow band spectral illumination as stimuli for measuring the color performance of a digital camera. A target method will involve the use of a physical spectrally and colorimetrically calibrated color test target under specific lighting conditions to measure the color performance of the camera.

The two methods contained in the standard for obtaining raw digital still camera characterization data will be described next. If little is known about the scene spectral content than the spectral method is preferred. However, in cases where scene spectral correlation statistics are well understood (e.g. the hardcopy colorants and the image capture illumination are pre-determined), then the target-based method is preferred.

Spectral sensitivity based characterization measurements shall be obtained by using a light source, with an output radiation where the power is a smooth function of wavelength (e.g. quartz-halogen), and a monochromator, with a spectral sampling interval that shall not be greater than 10nm and should not be greater than 5nm, to evenly illuminate a diffuse transmissive or reflective surface with selected wavelengths. The camera shall have the following 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 shall be disabled, compression shall be minimized, white balancing shall be fixed, the flash should be disabled, and all user settings shall be recorded.

The diffuse surface shall be lit by the monochromator, so that it fills the field of view of the digital camera. Capture images of the illuminated surface at wavelengths ranging from 360nm to at least 830nm and preferably to 1100nm in 10nm or smaller increments. The images shall be captured with the digital still camera lens and any filters used for general picture taking. Integrated relative radiance measurements, as a function of wavelength, of the illuminated surface shall be obtained and recorded for each selected wavelength using a radiance or irradiance meter. Apply an inverse OECF, which can be obtained using ISO standard *14524, Photography – Electronic still picture cameras – Methods for measuring the opto-electronic conversion functions (OECFs)*, summarized on page 29, to linearize the raw digital camera responses at each wavelength. Then average a 64 x 64 pixel block of values at the center of each image to determine the linearized digital camera response at each wavelength. Finally, calculate the relative spectral sensitivities at each wavelength for each color analysis channel by dividing the linearized digital camera response by the relative surface radiance. Normalize the spectral sensitivities so the sum of the green channel sensitivities is unity and report this resulting data in tabular form.

The target based characterization method consists of imaging a reflective or transmissive color target of known spectral and colorimetric characteristics, under specified illumination. The spectral data for each patch of the color test target shall be from at least 380nm to 730nm and should be from 360nm to 830nm, at least every 10nm.

An informative annex in the standard describes some of the characteristics that the test target should have. The standard gives the 24 patch Color Checker and the 237 patch Color Check DC Digital Camera Reference Chart as examples of test targets that may be used. The spectral power distribution for illuminating the test target shall be D_{55}. The illuminance at the target plane should be between 2000 lux and 4000 lux and have a maximum variation of 1% over the area being imaged. An additional informative annex in the standard outlines a recommended laboratory set-up for photographing a color reflection test target. At least two illumination sources shall be used to illuminate the target at 45° relative to the normal of the surface of the test target.

The target should fill the field of view of the camera and be in sharp focus. The flash shall be turned off, any automatic gain control shall be disabled, compression shall be minimized, white balancing should be fixed, and all user settings shall be recorded. At least three images of the color target shall be recorded. The mean and standard deviation of the digital still camera digital code values shall be obtained for each channel corresponding to the central area of each patch. This data shall be recorded for subsequent processing, which is described in *Part 2: Methods for determining transforms from raw DSC to scene-referred image data*, along with measured patch data, the spectral power distribution of the illumination, the OECF used for analysis, and other information about the target and camera used.

In order to guarantee the colorimetric reproduction, a set of camera sensitivity curves must be a linear transformation of color matching functions. An informative annex in the standard describes a digital still camera / sensitivity metamerism index (DSC/SMI) designed to give a measure for such potential color error. The indices consist of two elements: average and special DSC/SMIs. Average DSC/SMI will give a measure of camera metamerism for ordinary reflective objects and special DSC/SMI is an optional measure by defining arbitrary objects depending on applications. Procedures for measuring both DSC/SMIs with both camera characterization methods, described above, are given in this annex.

ISO 17321-2, Graphic Technology and photography – Colour characterization of digital still cameras (DSCs) – Part 2: Methods for determining transforms from raw DSC to scene-referred image data

The spectral responses of the color analysis channels of digital still cameras do not, in general, match those of a typical human observer. Nor do the responses of different digital still cameras ordinarily match each other. In characterizing these cameras, it is therefore necessary to take account of their spectral sensitivities, illumination, and encoding color space. Part 2 of this unpublished standard, which is discussed here, specifies methods for the determination of such characterization transforms from raw digital still camera image data to scene-referred image data based on the minimization of errors in a scene analysis color space based on CIE colorimetry. The digital still camera characterization data obtained in *Part 1: Stimuli, metrology, and test procedures* can serve as the raw image data used in this part of the standard.

Three alternative methods are described for obtaining characterization transforms. The first method takes advantage of the pre-defined colorant and illumination characteristics encountered when scanning hardcopy originals to produce transforms specifically for that capture condition. The second method takes advantage of some set of statistically expected assumptions about the spectral characteristics of the scene or original (e.g. artwork captured in a studio with know uniform illumination) being captured to produce characterization transforms that are more reliable where these assumptions hold true. Method three makes no assumptions about scene spectral correlation statistics, and is the most robust to highly variable natural scene capture under different illumination sources. For the first two methods, the digital still camera data can consist of captured test target patch values or spectral characterization data. Method three requires spectral data for the determination of characterization transforms.

With each method, the characterization transformation determination procedure shall be as follows. First, determine the class of scene analysis to select the appropriate characterization transformation determination method. Second, obtain the raw digital still camera characterization data. Third, determine the inverse camera OECF, from the OECF measured according to ISO standard *14524, Photography – Electronic still picture cameras – Methods for measuring the opto-electronic conversion functions (OECFs)*, summarized on page 29, and use it to linearize the raw digital camera characterization data. Next, select the scene analysis error minimization color space, and patch or wavelength error weights (if any). Then, determine the aim patch or spectral values in the scene analysis error minimization color space. Finally, determine the color characterization transformation matrix, that when applied to the linearized raw data to transform it to the scene analysis color space, produces the smallest weighted mean error in the scene analysis error minimization color space.

Only the second method will be described here in more detail, since it relates the closest to the digital capture of three-dimensional cultural heritage. This method assumes that all colors analyzed will have relatively smooth spectra consistent with surface reflectance colorants. Either the spectral-based or target-based methods in *Part 1* can be used to obtain the raw characterization data. If spectral characterization data is used, the signals that target samples would create should be calculated from the spectral characterization data. The adopted white should be a perfectly reflecting diffuser illuminated identically to the test chart. The recommended scene analysis error minimization color space is CIELAB. An informative annex in the standard gives considerations for scene analysis error minimization color space selection. The samples should be equally weighted, unless the matrix is not constrained to be white point preserving, in which case, the neutral samples should be given higher weights, or experience indicates that certain colors should be given higher weights, either because they are analyzed with larger errors, or are accuracy-critical. The row sums of the matrix should be constrained to enforce white point preservation. The matrix should be normalized so that the middle row sum is unity for reporting. The characterization transformation reported shall consist of the inverse OECF for each channel, the normalized matrix, the adopted white, the sample weights used (if any), and a description of the scene analysis error minimization color space according to ISO standard *22028-1, Photography and graphic technology – Extended colour encodings for digital image storage, manipulation and interchange – Part 1: Architecture and requirements,* summarized on page 41. The weighted mean error magnitude in the scene analysis estimates, as expressed in the scene analysis error minimization color space, may additionally be reported as the scene analysis error index.

ISO 22028-1, Photography and graphic technology – Extended colour encodings for digital image storage, manipulation and interchange – Part 1: Architecture and requirements

A fundamental choice for any imaging system architecture is how to represent images numerically, in what color space and with what digital encoding. It is necessary to unambiguously describe the meaning of the color values used to encode digital images.

The color encoding definitions need to not only include a specification of the relationship between the digital code values and corresponding physical color values, but they also need to clearly specify any other information needed to unambiguously interpret the color values. This unpublished standard specifies a set of requirements to be met by color encodings defined for various digital-imaging applications involving digital image storage, manipulation, and/or interchange. It also describes a reference image-state-based digital imaging architecture that is flexible enough to support a wide variety of applications and workflows and can be used to classify extended color encodings into a number of different image states.

One important aspect of a digital imaging architecture is how the digital image data is encoded as it progresses through the system workflow from image capture/creation through image processing/storage/interchange, and finally to output on one or more output devices. The standard defines scene-referred color encodings and picture-referred color encodings, which can be subdivided into original-referred and output-referred color encodings. Scene-referred color encodings are representations of the estimated color-space coordinates of the elements of an original scene. Picture-referred color encodings are representations of the color-space coordinates of a hardcopy or softcopy image. Original-referred color encodings are representations of color-space coordinates of a two-dimensional hardcopy or softcopy input image. Output-referred color encodings are representative of the color-space coordinates of image data that is appropriate for a specified real or virtual output device and viewing conditions. Also defined in the standard are color rendering transforms, which are used to transform a scene-referred image to an output-referred image, color re-rendering transforms, which are used to transform an original-referred image to an output-referred image, and also film rendering and unrendering transforms.

Color encodings can be specified at two levels. A color space encoding includes the specification of a digital encoding method. A color image encoding further includes any additional information necessary to properly interpret the image color values, such as the image state, the image viewing environment and the reference imaging medium.

Information needed to define a color space is given in the standard for three types of color spaces: colorimetric (e.g. CIE color spaces, additive RGB color spaces, luma-chroma color spaces derived from additive RGB color spaces), color appearance (e.g. CIECAM97s) and device-dependent (e.g. input and output device-dependent color spaces).

Defining a color space encoding requires the identification of a color space as well as a digital encoding method. Both a forward and inverse encoding transform shall be specified. Digital encoding methods will typically be integer digital encoding methods, although floating-point digital encoding methods will be useful in certain applications. The definitions of each of these digital encoding methods are given in the standard.

Information needed to define a color image encoding includes the identification of a color space encoding, together with the specification of the image state (scene-, original-, or output-referred), a reference image viewing environment in which the image is intended to be viewed (including the image surround, assumed adapted white point, luminance of adapting field, and viewing flare), and the set of valid color values in the color space encoding. Color image encodings intended for an output-referred image state shall also define the characteristics of a reference imaging medium.

An informative annex in the standard gives examples of a number of different workflows commonly encountered in digital photography and graphic technology. They include generic workflows for digital photography, digital cameras producing CRT-ready images, copy stand photography, scanning hardcopy, hardcopy scanners producing CRT-ready images, scanning color negatives, and video imaging systems. A second informative annex in the standard lists some characteristics of some existing color encodings (e.g. sRGB, sYCC, ROMM RGB, RIMM RGB) for comparison. In a third informative annex in the standard, a set of guidelines for making the appropriate selection of color encodings for image storage, manipulation and interchange in digital photography and graphic technology applications are specified. The selection criteria include: the image state associated with the color image encoding, the extent of its color gamut, its luminance dynamic range, the ability of a color encoding to represent image values brighter than a "perfect white", the quantization error associated with the discrete nature of the digital color values, the quantization efficiency, the visual uniformity of the color encoding, the complexity of conversions to other important color encodings, its compressibility, its compatibility with existing industry practice, and hue shifts induced by nonlinear tone scale manipulations.

4. IEC

The IEC is an international standards body made up of a network of national standards institutes from 62 countries that prepares and publishes standards for electrical, electronic, and related technologies.

IEC 61966-2-1, Multimedia systems and equipment – Colour measurement and management – Part 2-1: Colour management – Default RGB colour space – sRGB

The standard color space, sRGB, is a simple and robust device-independent color definition. It is suited for CRT and flat panel displays, television, scanners, digital cameras, and printing systems. The three factors of this RGB space are the colorimetric RGB definition, the simple exponent value of 2.2, and well-defined viewing conditions. It serves the needs of personal computer and World Wide Web-based color imaging systems, and is based on the average performance of personal computer displays. There are two parts to the methodology described in the standard; the encoding transformations and the reference conditions. The encoding transformations provide all of the necessary information to encode an image for optimum display in the reference conditions.

The reference image display system is a computer controlled CRT display with a luminance level of 80cd/m^2, a white point of D_{65} (x=0.3127, y=0.3290), a model offset (R, G and B) of 0.0 and an input/output characteristic (R, G and B) of 2.2. The CIE chromaticities of the red, green and blue reference display primaries are listed in the standard. The reference viewing conditions are derived from ISO standard *3664, Viewing conditions for graphic technology and photography*. Specifically, the reference ambient illuminance level shall be 64lx, the reference background and proximal field shall have a luminance level of 16 cd/m^2 and an average chromaticity of illuminant D_{65}, the reference surround shall have a luminance level of 4.1cd/m^2 and an average chromaticity of illuminant D_{50}, the reference ambient white point shall be illuminant D_{50}, and the reference veiling glare shall be 0.2cd/m^2. The reference observer shall be the CIE 1931 2° standard observer.

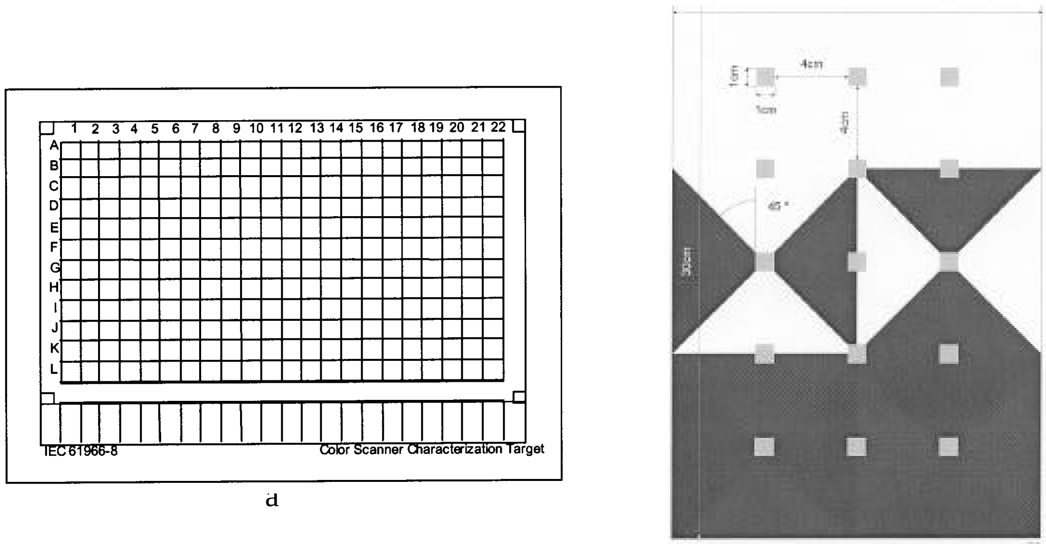
The encoding transformations between CIE 1931 XYZ tristimulus values and 8-bit RGB values provide unambiguous methods for representing optimum image colorimetry when viewed on the reference display in the reference viewing conditions by the reference observer, and as measured on the faceplate of the display, which assumes the absence of any significant veiling glare. The transformation from RGB values to CIE XYZ values and the reverse transformation are outlined in the standard.

One of the informative annexes in the standard describes usage guidelines for the sRGB color space when it is used with or without ICC profiles in color management applications. It also describes several different scenarios to consider when dealing with palletized images and displays. In two other informative annexes in the standard, recommendations are given for situations where the viewing conditions are different than the reference viewing conditions. Amendment 1 of the standard consists of three additional annexes. The first annex standardizes a default transformation between sRGB and a standard luma-chroma-chroma color space, sYCC. The same reference conditions are shared by both color spaces. The second annex provides equations necessary for extended gamut encoding for sRGB, called bg-sRGB, and its YCC transformation, called bg-sYCC. The transformations between these color spaces and sRGB, YCC and CIE 1931 XYZ are given. The third and final annex gives equations for describing the relationship between sRGB and L*a*b* coordinates.

IEC 61966-8, Multimedia systems and equipment – Colour measurement and management – Part 8: Multimedia colour scanners

This standard provides a way of obtaining colorimetric characterization data of color scanners, which is necessary for color management in open multimedia systems. The mulitmedia color scanner characterization of the standard focuses on the characterization of spectral transfer functions of the three channels as multiband sensitivities and achromatic tone characteristics. Further objective performance assessment can be performed using methods, which are also described in the standard.

The standard assumes that the originals, which will be scanned, are reflective. Even though the standard is geared toward scanner characterization, most of the methods described, which are different from the methods described in *Part 9: Digital cameras*, summarized on page 50, can be used to characterize digital cameras as well. These particular methods will be the focus of this summarization. Figures 6 a and b show two test targets used in the standard.



a

b

Figure 6 a, b: a) Color and grayscale target, b) Target for measurement of spatial cross-talk.

The spectrophotometer, with a minimum wavelength range of 400nm to 700nm, an interval of 10nm, and a geometry of either 45/0 or 0/45, shall be used for the measurements. A one-shot spectroradiometer, with a minimum wavelength range and interval that is the same as for the spectrophotometer, shall be used to measure the spectral distribution of the light source. Figure 6a shows the reflective target used for some of the measurements made in the standard, where the top part of the target consists of color patches and the bottom part consists of gray patches.

The spectroradiometer shall be used to measure the spectral power distribution of the light source and the data shall be reported in tabular and graphical forms. The tone characteristics shall be measured as follows. First, the spectral reflectance of each gray patch of the target shall be measured using the spectrophotometer. Then, the target shall be captured 10 times and the red, green and blue data shall be determined by averaging the picture elements in the center of each gray patch for each image and then the average values of the 10 images shall be averaged. The measured and averaged data shall be normalized and recorded. A 4^{th} order polynomial characterization is performed on this data and the results are reported in graphical form as light flux vs. output data. The equations for calculating the inverse tone characteristics, which represent the polynomial transformation from normalized output data to captured light flux of the red, green, and blue channels, are also given in the standard.

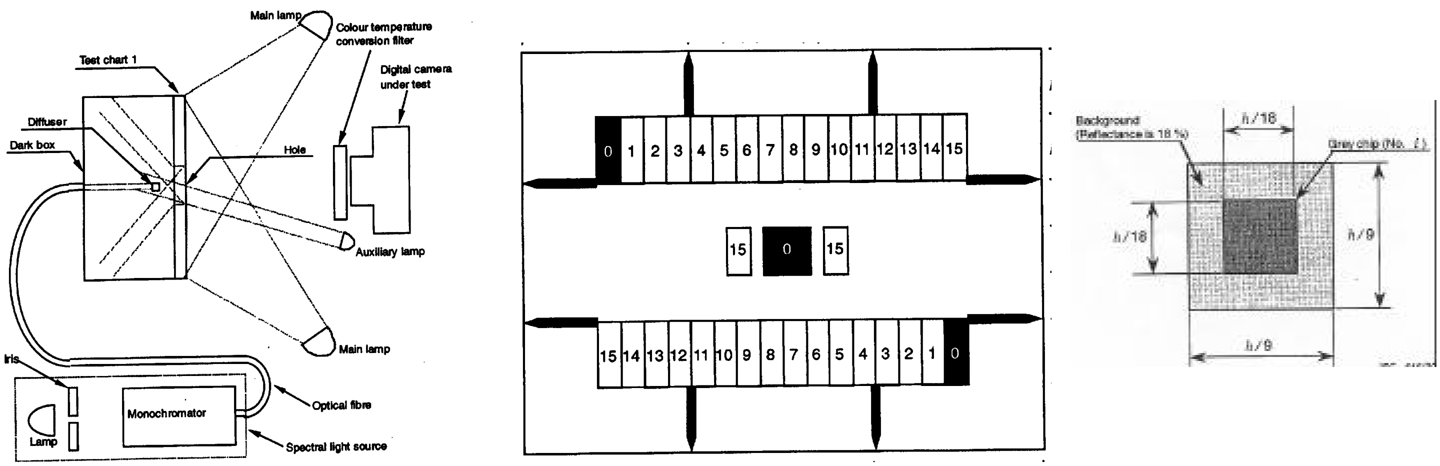
The spectral responsivity characteristics of the device are measured as follows. First, the spectral reflectances of each color patch of the target shall be measured. Next, the target shall be captured 10 times and the red, green and blue data shall be determined by averaging the picture elements in the center of each color patch for each image and then the average values of the 10 images shall be averaged. Then, the normalized light flux values shall be calculated. The multiband spectral responsivity characteristics for the red, green, and blue channels shall be estimated using the spectral reflectances of the color patches, the spectral power distribution of the light source, and the averaged and normalized red, green, and blue channel output data. The algorithm for performing this estimation is described in an annex in the standard. The spectral responsivity data shall be reported both in tabular and graphical form. The overall responsivity characteristics shall also be reported taking into account the spectral power distribution of the light source. Examples for the application of the spectral characteristics are given in an informative annex in the standard, specifically for the calculation of the ICC profiles and the calculation of an optimized conversion for the sRGB color space.

A method for measuring spatial non-uniformity is also described in the standard. A gray sheet of paper with reflectance between 60% and 80% shall be used for the measurements as the target. After this target is captured so that it fills the image, the mean and mean square deviation values shall be determined from 25 equally spaced image areas. Alternatively, the tristimulus values and color differences in either the CIE 1976 UCS or CIELAB space shall be calculated. These results shall be reported as indices of non-uniformity, along with the reflectance of the uniform gray target. A method for characterizing the instability of output data upon turning on the multimedia color scanner is also described in the standard.

Large area spatial cross-talk is the dependency of the output digital data of a color patch on the reflectance of surrounding areas. It can be measured using the target shown in Figure 6b. The target shall be printed on a sheet of non-fluorescent paper and the 15 square test patches shall be uniform gray with reflectance between 20% and 40%. The white areas of the target are the surface reflectances of the paper and the black areas are printed at the maximum density of the printing system. The target shall be captured three times in one direction and three times after being rotated 180°. The mean values of each gray patch of all six images shall be recorded. The mean data values of all 15 patches shall be determined for each color channel and recorded, along with the relative difference between the maximum and minimum values and the relative root mean standard deviations resulting from all of the patches, both calculated as percentage points for each color channel.

IEC 61966-9, Multimedia systems and equipment – Colour measurement and management – Part 9: Digital cameras

This standard defines test charts, measurement conditions and methods of measurement for assessing the color reproduction of digital cameras used to capture color still and moving images for use in multimedia applications. Figures 7 a, b, and c show both an equipment arrangement and test charts used in the standard.



a b c

Figure 7 a, b, c: a) Equipment arrangement for measurements, b) Test chart, c) Test chart with replaceable chip.

All measurements specified in the standard shall be carried out in a dark room. Figure 7a shows the configuration of the equipment used for measuring the tone and spectral responsivity characteristics of the digital camera and the spectral distribution of the built-in electronic flash. The conditions of this configuration are as follows. The test charts that are used in this configuration are shown in Figures 7 b and c, where patches marked 1 through 15 are gray patches, with reflectances that are defined in the standard, and patches marked 0 are holes. The illumination of the test charts shall be performed by two or four main lamps, which shall be 45° relative to the surface of the test chart, and one auxiliary lamp, which illuminates the diffuser in Figure 7a. These lamps shall be halogen lamps. The main lamps shall not be directly illuminating the diffuser. The correlated color temperature of the lamps shall be 3100K ± 100K. The non-uniformity of illumination shall be less than 5%. The average illumination on the test chart shall be 2000lx ± 100lx. The camera shall be placed normal to the test chart. The test chart shall fill the frame of the camera when captured. The spectral light source in Figure 7a consists of a halogen lamp, an iris, a monochromator and an optical fiber with a diffuser. Specifications of these parts are listed in the standard, for example, the wavelength range and spectral bandwidth of the monochromator shall be 380nm to 780nm and 5nm, respectively. A color temperature conversion filter used to achieve a color temperature of 5500K ± 300K shall be used over the camera lens, where needed in the standard. The reflectance of the inside of the dark box shall be less than 2%.

The radiance meter used for the measurements of the output from the spectral light source is specified in the standard. Its wavelength range should be from 380nm to 780nm. A spectroradiometer can also be used for this measurement and should be used for measuring a built-in electronic flash. Its specifications are also listed in the standard. It shall have a wavelength range of 380nm to 780nm and a bandpass of 5nm or less. A luminance meter shall be used for measuring in the standard. Its specifications are also listed in the standard. Alternatively, a colorimeter with luminance output in Y can also be used for the luminance measurement.

For the measurement of the tone characteristics, the equipment shall be as arranged in Figure 7a. The optical fiber shall be removed, the auxiliary lamp shall be switched off, and the hole at rear side of the dark box shall be covered with a lid painted black like the inside of the box. Two separate measurements shall be made, one with each color temperature (5500K and 3100K). The test chart shown in Figure 7c shall be inserted into the hole at the center of the test chart shown in Figure 7b sequentially with gray chips i = 0 to 15, where i = 0 is a hole. The luminance of each gray chip shall be measured and captured with the digital camera. The mean red, green and blue digital value data shall be recorded for each gray chip image. The mean values of the upper gray steps shall also be noted for each image. The recorded data shall be compensated to eliminate any autonomous exposure control or errors of a mechanical shutter of the digital camera. The measured and calculated data shall be presented in both tabular and graphical form, along with the effective correlated color temperature of the illumination.

The measurement of the spectral responsivity characteristics of the digital camera are performed as follows. First, the intensity of the auxiliary lamp, with the iris shut, shall be adjusted so that the digital image data corresponding to the diffuser is around 20% of a full data range of the digital camera. Next, with the auxiliary lamp still on, the iris shall be adjusted once so that the maximum data in the red, green and blue channels are between 70% and 80% inclusive of the full scale. Two separate measurements shall be made, one with each color temperature (5500K and 3100K). Next, the radiance on the diffuser from the spectral light source shall be measured using the radiance meter with the auxiliary lamp switched off. Then, with the auxiliary lamp switched on and the iris shut, the digital image data corresponding to the diffuser shall be recorded, pixel-by-pixel, for each color channel. Next, the iris is opened and the test chart is captured by the digital camera, with the diffuser lit at each of the 81 wavelengths from 380nm to 780nm in 5nm intervals. The digital image data for each image shall be recorded pixel-by-pixel for each color channel. Also, the mean values of the upper gray steps shall also be noted for each image for each color channel. Finally, the auxiliary lamp shall be switched off and the test chart shown in Figure 7c with gray chip 8 shall be inserted into the front hole in the center of the test chart shown in Figure 7b. The spectral distribution characteristics shall be measured using the spectroradiometer with the diffuser lit at each of the 81 wavelengths from 380nm to 780nm in 5nm intervals. The pixel-by-pixel data shall be compensated to eliminate any autonomous exposure control or errors of a mechanical shutter of the digital camera, linearized using the tone characterization data, and averaged over the center portion of the image corresponding to the monochromatic radiation. The radiance of the spectral light source is then taken into account. This data shall be reported in electronic and graphical forms, together with the effective correlated color temperature.

The method for measuring the spectral distribution of the built-in electronic flash that is described in the standard will not be discussed here. The spatial non-uniformity of the digital image data shall be measured by photographing an evenly illuminated uniform white chart. The white chart shall be illuminated by two lamps that are 45° relative to the surface of the chart. The color temperature conversion filter shall be placed over the camera lens in order to achieve an effective correlated color temperature of 5500K. . After this target is captured so that it fills the image, the mean digital image values shall be determined from 25 equally spaced image areas for each color channel. The R, G, and B data shall be converted to the tristimulus values X, Y, and Z in accordance with *Part 2-1: Colour management – Default RGB colour space – sRGB*, summarized on page 44. Color differences in either the CIE 1976 UCS or CIELAB space shall be calculated as indices of non-uniformity and shall be reported as a table.

In an informative annex in the standard, an example is given for the use of the reported results for color management. In another informative annex, recommendations are given for the automatic extraction of data from the test chart image.

5. ANSI

ANSI is a private, non-profit non-governmental organization that administrates and coordinates standards developed in the United States. It is supported by both private and public organizations. ANSI is the official United States representative to both the ISO and IEC.

ANSI IT8.7/2, Graphic technology – Color reflection target for input scanner calibration

This standard defines an input reflection test target that will allow any color-input scanner to be calibrated with any film dye set used to create the target. Although this test target is intended for use with scanners, it can also be photographed with digital cameras, which is why its description in the standard is pertinent to the topic of this standards review. In the design of the test target, which is printed on photographic paper, the colors of the target patches were chosen most effectively by uniform spacing of hue, lightness, and chroma in the CIELAB color space based on the D_{50} illuminant and the CIE 2° standard observer. The color gamut of the test target is common to most of the commonly used color photographic paper dye sets. The Kodak Q-60 target, which uses 12 uniformly spaced hue angles in CIELAB sampled at three chroma values at each of three lightness levels, was adopted as this target with the addition of a fourth product-specific maximum chroma value at each hue angle/lightness combination. Also included in the target were scales in each of the individual dyes, dye pairs, and a dye neutral, the product minimum and maximum densities, and a “vendor-optional” area where the target manufacturer could add unique elements beyond those defined in the standard. Manufacturing tolerances specified in the form of ΔE units are also defined for the test target in the standard. All of the non-image areas of the target shall be approximately neutral with a lightness L* of approximately 50.

The physical layout of the test target is described in detail in the standard. Figure 8 shows the layout of the IT8 target.

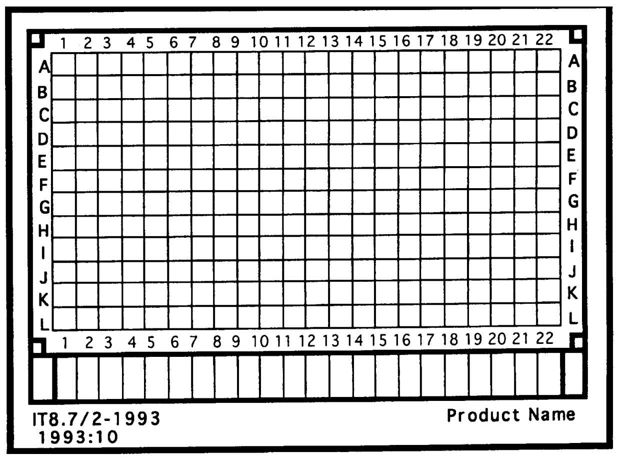


Figure 8: Layout of color reflection input calibration target.

The standard also specifies that calibrated test targets shall be measured using a reflection spectrophotometer with a measurement geometry of 0/45 or 45/0. During measurement, the sample shall be backed with a black material with a density of at least 1.5. Tristimulus values shall be calculated based upon a 2° standard observer and the D_{50} illuminant, with no greater than a 10nm data interval and a bandpass equal to the measurement interval. The mean and standard deviation values shall be reported as X, Y, Z tristimulus values to two decimal places. The mean values shall also be provided as CIELAB and standard deviation as CIE ΔE^*_{ab}. The file format shall be an ASCII format keyword value file. The required keyword fields, values, and data format identifiers are listed in the standard. Also, the standard states that each test target manufacturer shall provide the monitoring procedure to be used for each target type.

In addition, an informative annex in the standard describes how to use this target for the application of calibrating a color scanner. There are two distinct ways in which a scanner may be operated. The calibration procedure for each is different. When the scanner is a “color digitizer,” its objective is to capture the color information of the original image being scanned for subsequent processing elsewhere. Therefore, the output data must have some unique relationship to the tristimulus values of the original. In the other case, when the scanner is a “gamut mapped color digitizer,” it is operated in a device dependent manner, so the output data must have some unique relationship to the tristimulus values of the reproduction. The calibrated input target will provide colors with known XYZ tristimulus values as an input to the color scanner. The primary objective of the target is to enable the user to calibrate his system using whatever calibration facility exists. For a colorimetric calibration, data obtained by scanning the target may be used to derive a transformation which maps the data back to the tristimulus values provided with the calibrated target or some transformation of them. The derivation of the transformation is application dependent. Helpful guidelines are listed in the annex of the standard. For a closed system calibration without a two-stage transformation using colorimetric data, the target is scanned and output on a specific device (e.g. monitor or printer). Visual assessment under controlled viewing conditions, possibly supplemented by color or density measurement, is often used to determine the quality of the match.

6. CIE

The CIE is an international standards body, which is recognized as such by the ISO. It is a technical, scientific, and cultural non-profit organization, which comprises of 38 member bodies. It is devoted to the cooperation and exchange of information among member countries on matters relating to lighting. The publications summarized below are referred to as technical committee reports, not as standards, so their purpose is to advise or recommend, but not mandate.

CIE 15.2, Colorimetry

This report provides a consistent and comprehensive account of the basic colorimetric recommendations of the CIE. The first recommendation given in this publication is the illuminants to be used for general colorimetry. They include illuminants A, B, C, D_{50}, D_{55}, D_{65}, and D_{75}. Their relative spectral power distributions are given in this report at 5nm intervals. A formula for calculating the relative spectral power distribution of daylight illuminants with correlated color temperatures from 4000K to 25,000K is also given. When fluorescent samples are involved, a D illuminant should always be used over illuminant C, because of its insufficient ultraviolet content. CIE sources for colorimetry are also listed for illuminants A, B, and C, which are artificial sources recommended when the illuminants are to be realized in a laboratory environment. There is no artificial source recommended to realize the D illuminants.

The publication recommends using pressed barium sulphate as a perfect reflecting diffuser, or standard of reflectance factor, because its reflectance is approximately equal to unity. For specifying reflecting samples, the following illuminating and viewing conditions, or geometries, are recommended: 45/0 (45°/normal), 0/45, d/0 (diffuse/normal), and 0/d. For transmitting samples, 0/0, 0/d, and d/d geometries are recommended.

The CIE 1931 standard colorimetric observer, or 2° observer, and the CIE 1964 supplementary standard colorimetric observer, or 10° observer, color-matching functions are given in this report from 360nm to 830nm in 1nm intervals. The formulas for calculating tristimulus values for both reflecting and transmitting objects, and self-luminous objects are also given, along with formulas for deriving chromaticity coordinates from tristimulus values.

This publication recommends the CIE 1976 Uniform Chromaticity Scale (UCS) diagram, the CIE 1976 L*u*v* (CIELUV) color space, and the CIE 1976 L*a*b* (CIELAB) color space as uniform color spaces. The formulas for calculating the coordinates for each uniform color space are listed, along with the Euclidean distance color difference equations for CIELUV and CIELAB.

In the final section of the report are recommendations concerning miscellaneous colorimetric practices and formulae. They include recommendations for defining dominant wavelength, complementary wavelength, colorimetric purity, excitation purity and forms of representing relationships between color stimuli, evaluating whiteness, and calculating special metamerism index: change in illuminant and correlated color temperature. A third edition is near completion at the time of writing this summary.

CIE 51, A method for assessing the quality of daylight simulators for colorimetry

This report provides a method for evaluating the suitability of a test source as a simulator of CIE Standard Illuminant D_{55}, D_{65}, or D_{75}. For each of these illuminants and the 10° standard observer, spectral radiance factor data are supplied for five pairs of non-fluorescent samples that are each metameric matches. The colorimetric differences of the five pairs are computed for the test illuminant. The visible range metamerism index is the average of these differences and is used as a measure of the quality of the test illuminant as a simulator for non-fluorescent samples for the visible wavelength range. For fluorescent samples, the ultraviolet range metamerism index, which is the average of the colorimetric differences computed with the test illuminant for three other metameric sample pairs, each consisting of a fluorescent and a non-fluorescent sample, is used. The fluorescent sample in each metameric pair is specified by values of spectral radiance factor, relative spectral distribution or radiance emitted by fluorescence, and spectral external radiant efficiency in the report.

The procedure for evaluating the suitability of a test source as a simulator of CIE Standard Illuminant D_{55}, D_{65}, or D_{75} is as follows. First, the spectral power distribution of the test source is determined by spectroradiometry. The radiometric quantity measured should be the spectral irradiance at the sample surface. The data must be presented in the form of the spectral concentration of irradiance of 5nm intervals and over 5nm bands from 300nm to 700nm. Sources with significant spectral irradiance at the sample surface for wavelengths less than 300nm are not suitable daylight simulators. Next, the spectral power distribution of the test source is normalized so that it is independent of the absolute level of illumination. Then, as a preliminary test, the chromaticity coordinates of the test source are evaluated to see if they fall within a circle of radius 0.015 from the centered chromaticity coordinates of the standard daylight illuminant concerned, in the CIE 1976 Uniform Chromaticity Scale diagram, u'_{10}, v'_{10}.

For the visible range metamerism index, first, the tristimulus values are calculated for the five metameric pairs using the normalized spectral power distribution of the test source and the 10° standard observer from 400nm to 700nm in 5nm intervals. Then, the color differences between the fives sets of tristimulus values are calculated using either the CIE 1976 L*u*v* or L*a*b* formula and, finally, the visible range metamerism index is calculated as the average of the five color differences (ΔE^*_{ab} or ΔE^*_{uv}).

The ultraviolet range metamerism index is determined by first calculating the spectral total radiance factor for the fluorescent sample part of each of the three metameric pairs using an equation given in the report. The calculation of the tristimulus values, color differences and ultraviolet metamerism index is the same as above for the visible range metamerism index.

The metamerism indices are interpreted by categorizing the test source from A to E, depending on the values of the metamerism indices and the color space used. The category for the visible range metamerism index is presented first and the ultraviolet range metamerism index second in the category rating. The correlation of these category ratings with the requirements for various practical applications must be determined by experience. For many applications, though, daylight simulators of category BC are found to be useful. The appendix in the report gives the assessment of a number of daylight simulators, using the procedure described here.

7. NISO

NISO is a non-profit association accredited by ANSI, which identifies, develops, maintains, and publishes technical standards to manage information in the digital environment. NISO standards cover the areas of information-related needs, including retrieval, re-purposing, storage, metadata, and preservation.

NISO Data Dictionary – Technical metadata for digital still images

Technical metadata is perceived as an essential component of any digitization initiative for short-term and long-term management purposes. Work to date on image metadata has focused on defining descriptive elements for discovery and identification. Little attention has been paid to defining the types of information that describe the capture process and technical characteristics of the digital images. Technical metadata must be recorded accurately and consistently to ensure that the image files remain useable well into the future. It is necessary to support two fundamental goals: to document history and to ensure that image data will be rendered accurately on output. This unpublished standard presents a comprehensive list of technical matadata elements required to manage digital image collections. The metadata descriptions in the standard are structured to accommodate practices associated with digital copy photography, such as the use of technical targets, as well as techniques related to direct digital photography of original scenes.

The design goals of the standard are that the metadata is interchangeable (applicable to many applications and assured to be constant over time), extensible and scalable (allows future needs for metadata to be fulfilled with limited disruption of current solutions), image file format independent (can be supported by many current and future file formats and compression mechanisms), consistent (usable in a variety of application domains and user situations), and network-ready (provides seamless integration with a broad variety of systems and services). This dictionary assumes that metadata mappings are needed to automate the collection of technical metadata. The design model assumes that NISO-compliant metadata will be stored outside the image.

The standard references two documents, which provide supplemental information. The first is *TIFF, Revision 6.0*. The TIFF (Tagged Image File Format) format is highly flexible and platform-independent, is supported by numerous image processing applications and is publicly available. The structure of the header includes a rich set of technical information important for long-term image retention. The second reference is *DIG35 Specification: Metadata for digital images, version 1.1, working draft*, provided by the Digital Imaging Group. This document contains a comprehensive description of a standard set of metadata for digital images, which is not limited to technical metadata, but also includes, for example, a recommended implementation model and intellectual property rights metadata.

The basic image parameter metadata fields, which are fundamental to the reconstruction of the digital file as a viewable image on displays, described in this dictionary, are as follows. The format information includes: the MIME type, byte order, compression scheme, compression level, color space, ICC profile information, and information about whether the image is stored using either strips or tiles (collectively termed as segments). The file information includes a unique image identifier, file size, type of error detection used (checksum), image orientation, the orientation in which the image should be presented to a conventional monitor, and the designation of the device, application, medium and/or viewing environment to render the image data.

The image creation, or descriptive, metadata, which document irreversible attributes of the analog-to-digital conversion process that may be used for future quality assessment of the image data, will be listed next. The descriptions of the image creation metadata in this dictionary include: the medium of the analog source material, a unique source identifier, the image producer, the host computer, the operating system and version, the classification of the device used to create the image, the scanning system information, the digital camera capture information, which includes the digital camera manufacturer, model, and camera capture settings (f-number, exposure time, brightness, exposure bias, subject distance, metering mode, scene illuminant and its color temperature, focal length of lens, flash information, lighting conditions, exposure index, focus used, and print aspect ratio selected by the user when the picture was taken), type of image sensor, date and time image was created, and methodology and rationale to digitize an object or collection.

The image performance assessment metadata, described next, serve as metrics to assess the accuracy of output and of preservation techniques, particularly migration. The spatial metrics metadata described in the standard include: sampling frequency, image width and length (in pixels), and the width and height of scanned object. The energetics metadata include: the number of bits per color component, the number of color components per pixel, the colormap (lookup table) information for palette-color images, the gray response curve for grayscale images, and the white point and primary chromaticities. Targets can be used to benchmark spatial and energetic information about the item of interest at the time of capture. Targets can be either external or internal to a digital image. Internal targets are included in the image of the object and external targets are captured in a separate session, which are tied to the image through metadata. The target metadata fields included in the standard are: the identification of the targets as either internal or external, the target manufacturer or organization, name, and version number or media, the path where the image of the target is located, the path of the file that contains the image performance data relative to the target, and the path of the file that contains the ICC color profile or other image management profiles.

Change history metadata documents processes, such as editing or transforming, applied to image data over the life cycle of the image. The following metadata descriptions contain a summary of image processing operations that may be used for future quality assessment of the image data. These metadata descriptions include: the date and time the image was processed, the information about the source image data, the producer of the processed image, the processing software and version, and the processing actions. The last metadata description in this dictionary is the documentation of the previous versions of the technical metadata if image transformation creates a new generation of the image.

8. Conclusion

The standards and reports summarized above were all developed by national and international standards committees and, therefore, by a consensus of professionals. The information contained in each standard's summarization relates closest to the topic of this standards review, which is defining target-based testing procedures for characterizing the color and spatial quality of trichromatic digital cameras, that can be used to digitally archive cultural heritage collections.

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