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Photography — Electronic still-picture imaging — Noise measurements

Photographie — Imagerie des prises de vue électroniques — Mesurages du bruit

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Contents

Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 42, *Photography*.

This fourth edition cancels and replaces the third edition (ISO 15739:2017), which has been technically revised.

The main changes are as follows:

— several terms and definitions have been modified, added, and deleted (see Clause 3);

— calculation procedures of camera noise, signal-to-noise ratios, and DSC dynamic range have been revised for measurement accuracy (see Clause 6);

— presentation of results has been specified expressly (see Clause 7);

— description of noise component analysis has been revised to be more detailed (see Annex A);

— measurement method of visual noise has been revised to model the human visual system more closely (see Annex B);

— method for removing low frequency variations from the image signals has been revised and changed from informative to normative processing (see Annex C);

— description of procedure for determining signal-to-noise ratio has been revised (see Annex D);

— introduction of perceptually uniform mapping of visual noise to noisiness JND has been added (see Annex F).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Noise is an important attribute of electronic still-picture imaging. If noticeable levels of noise exist in the images captured by a camera, then detail textures of objects are lost in reproduction and the visibility of the images is degraded. Therefore, measurement methods for noise are very important and are needed to provide important information relevant to evaluating image fidelity and the visibility of noise in captured images. Measurement methods are also important for assessing camera performance relative to these image quality factors.

The primary sources of noise in captured images are photon shot noise, dark current shot noise, analogue processing readout noise of image sensors, and quantization noise of A/D converters. This type of noise source adds spatially random noise to captured still images, whose spatial pattern differs from frame to frame. The other type of noise source includes dark current pattern noise, row/column pattern noise, and photo response non-uniformity of image sensors. This type of noise source also introduces spatially random noise in captured images; however, its spatial pattern does not change under the same shooting conditions.

The noise level introduced by these sources in output images is highly dependent on shooting conditions, such as the camera exposure time, aperture value, and ISO sensitivity. Camera operating temperature is also an influential factor. Some camera processing, such as contrast amplification and noise reduction, heavily influence the noise spectrum, in addition to the noise level itself.

The image quality metrics described in this document are determined from the measurement of spatially distributed noise in the output still image that is viewed by an observer. The metrics include the effect of the internal camera processing on the spectrum and level of the noise.

When observers view output images, several factors affect how they perceive noise in images, in addition to the noise level itself. Observers view noise differently depending on the apparent tone of the area being viewed, the luminance and colour channels where noise exists, the noise spectrum, and the viewing conditions.

This document specifies methods for measuring noise and related metrics of digital still cameras accounting for these influential factors. Measurement conditions are specified to minimize the influence of disturbance factors, to ensure that temporal and spatial statistical property changes are negligible, and to provide a good estimate of the noise level.

The main body of this document specifies methods for measuring input-referred noise, signal-to-noise ratios, and DSC dynamic range. Noise is determined as an estimate of the perceived noise computed using root mean square values measured in image signals linearized from the camera output signals. The two types of spatially random noise, temporal and fixed pattern, are determined using a noise component analysis applied to multiple captured images, the details of which are provided in Annex A.

Annex B describes a procedure for measuring the visual noise (an output-referred noise metric) using a human visual model that aims to predict the perceived quality of the image. The model weights spectral components of the noise and takes into account the noise spectrum, viewing conditions, and the perceived difference between luminance and colour channels. The metric has been shown to provide a high level of correlation with human perception of noise in images.

Low frequency variations may be introduced in the captured image due to lens shading and non-uniform test chart illumination. Since these variations can influence the noise measurement a method for removing low frequency variations from the image is provided in Annex C.

Annex D provides a recommended step-by-step procedure for determining the signal-to-noise ratio.

Annex E describes recommendations for practical viewing conditions for various output media.

Annex F introduces perceptually uniform mapping of visual noise to noisiness JND.

Photography — Electronic still-picture imaging — Noise measurements

1 Scope

This document specifies methods for measuring and reporting the noise versus signal level and dynamic range of digital still cameras. It applies to both monochrome and colour electronic digital still cameras.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 554, *Standard atmospheres for conditioning and/or testing — Specifications*

ISO 7589:2002, *Photography — Illuminants for sensitometry — Specifications for daylight, incandescent tungsten and printer*

ISO 12232:2019, *Photography — Digital still cameras — Determination of exposure index, ISO speed ratings, standard output sensitivity, and recommended exposure index*

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

ITU-R BT.709-6, *Parameter values for the HDTV Standards for production and International programme exchange*

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

IEC 61966-2–1/Amd.1:2003, *Multimedia systems and equipment — Colour measurement and management — Part 2-1: Colour management — Default RGB colour space — sRGB — Amendment 1*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
camera opto-electronic conversion function
camera OECF
relationship between the input scene log luminances and the output pixel values for an opto-electronic digital capture system

Note 1 to entry: The unit of luminance (L) is cd/m^2. Log luminance is dimensionless, expressed as $\log_{10}(L/L_0)$, where L_0 = 1 cd/m^2.

3.2
clipping value
pixel value that remains constant for further increases in exposure (highlight clipping value) or for further decreases in exposure (dark clipping value)

3.3
digital still camera
DSC
camera that produces a digital still image from the digitized output of a solid-state photo sensor and records the digital still image using a digital memory, such as a removable memory card

3.4
DSC dynamic range
ratio of the input signal (luminance or exposure) saturation level to the minimum input signal level that can be captured with a signal-to-temporal noise ratio of at least 1

3.5
exposure time
total time period during which the photo sensor is able to integrate the light from the scene to form an image

3.6
focal plane opto-electronic conversion function
focal plane OECF
relationship between the input focal plane log exposures and the output pixel values for an opto-electronic digital image capture system

Note 1 to entry: The unit of exposure (H) is lx·s. Log exposure is dimensionless, expressed as $\log_{10}(H/H_0)$, where $H_0 = 1$ lx·s.

3.7
image sensor
electronic device which converts incident electromagnetic radiation into an electronic signal

Note 1 to entry: A complementary metal oxide semiconductor (CMOS) image sensor and a charge coupled device (CCD) image sensor are examples of image sensors.

3.8
noise
unwanted variations in the response of an imaging system

3.8.1
total noise
all the unwanted variations, consisting of *fixed pattern noise* (3.8.2) and *temporal noise* (3.8.3), of the values in the image signals captured by a single exposure

Note 1 to entry: The procedure in this document for calculating the total noise requires multiple frames.

3.8.2
fixed pattern noise
FPN
unwanted spatial pixel variations of the values in the image signals which remain constant from frame to frame given the same illumination, aperture value, integration time, and ISO sensitivity setting

Note 1 to entry: Most fixed pattern noise (FPN) varies in digital number with sensor gain and ISO sensitivity setting and cannot, therefore, be considered static relative to exposure. There are three classes of fixed pattern noise, (1) static with integration time, for example, pixel FPN, column FPN and row FPN, (2) varies with integration time, for example dark current FPN, but static from frame to frame, and (3) signal dependent FPN such as photo response non-uniformity (PRNU), but still static from frame to frame.

Note 2 to entry: PRNU is a pixel to pixel gain mismatch. It is normally expressed as a percentage of signal because it is a gain error. It is static from frame to frame and, thus, contributes to fixed pattern noise but its magnitude is a function of signal level. It is, therefore, considered as a signal dependent FPN.

3.8.3
temporally varying noise
temporal noise
unwanted variation in the values of the image signals that changes from frame to frame due to sensor dark current shot noise, photon shot noise, analogue processing, and quantization

3.9
noise spectrum
curve or equation which expresses the image noise as a function of two-dimensional image spatial frequencies

3.10
saturation
condition where the camera output signal reaches the maximum valid (not clipped or bloomed) value

3.10.1
exposure saturation
minimum focal plane exposure that produces the maximum valid (not clipped or bloomed) camera output signal

Note 1 to entry: The exposure saturation is expressed in lux-seconds (lx·s).

3.10.2
luminance saturation
minimum scene luminance that produces the maximum valid (not clipped or bloomed) camera output signal

Note 1 to entry: The luminance saturation is expressed in candelas per square meter (cd/m^2).

Note 2 to entry: The luminance saturation is determined for a fixed exposure setting of the camera under test.

3.11
signal-to-noise ratio
ratio of the input signal (luminance or exposure) level to the root mean square (rms) noise level, at a particular signal level

Note 1 to entry: In this document, the output pixel value is converted to an input signal level by applying the inverse OECF. The average of the input signal levels corresponds to the scene luminance (focal plane exposure) value when capturing an image. Unwanted variations exist in the converted input signal level that are centred about its average. This variation in input signal level is noise and is measured as the rms value.

Note 2 to entry: This is typically expressed as a graph or table showing the signal-to-noise ratio versus input signal level for the full range of input signal levels.

3.12
test density
spectrally non-selective transmittance filter used to reduce an input luminance to a predefined ratio of the unfiltered luminance

4 Test conditions

4.1 General

The following measurement conditions should be used as nominal conditions when measuring the noise of a DSC. If it is not possible or appropriate to achieve these nominal operating conditions, the actual operating conditions shall be listed along with the reported results.

4.2   Illumination

4.2.1   Characteristics

The noise measurements shall indicate whether illumination conforming to the standard photographic daylight or tungsten illuminant was used. ISO 7589 describes the procedures for determining if the characteristics of the illumination used in a specific noise determination test are an acceptable match to the standard photographic daylight and tungsten illuminants.

4.2.2   Daylight illumination

For daylight measurements without the camera lens, illumination conforming to the ISO sensitometric daylight illuminant specified in ISO 7589:2002, Table 1 shall be used. This illuminant is defined as the product of the spectral power distribution of CIE Illuminant D55 and the spectral transmittance of the ISO standard camera lens. For measurements with the camera lens in place, the spectral characteristics of the illumination shall conform to CIE illuminant D55.

4.2.3   Tungsten illumination

For tungsten measurements without the camera lens, illumination conforming to the ISO sensitometric tungsten illuminant specified in ISO 7589:2002, Table 2 shall be used. This illuminant is defined as the product of the average spectral power distribution of experimentally measured sources having a colour temperature of approximately 3 050 K and the spectral transmittance of the ISO standard camera lens. For measurements with the camera lens in place, the spectral characteristics of the illumination shall conform to the average spectral power distribution of experimentally measured sources having a colour temperature of approximately 3 050 K.

4.2.4   Uniformity of illumination and reflection test chart illumination geometry

The illumination should meet the uniformity requirements of the measurement procedures described in Clause 5. For reflection test charts, the sources are positioned so that the angular distribution of influx radiation is at its maximum at 45° to the test chart normal, and is negligible at angles of less than 40° or more than 50° to the normal, at any point on the test chart.

Additional shielding of the camera may be necessary to prevent stray illumination from the light sources, or from other reflections, entering the camera lens. The illuminance incident on reflection charts, or the luminance used to illuminate transmission charts, shall not vary by more than 2 % from the mean value over the surface area of the chart as defined in ISO 14524.

NOTE   In particular, if a transmissive chart is used, light from the chart can reflect off the camera or camera operator back to the surface of the chart and be imaged by the camera. Such reflections need to be avoided. This can be accomplished by shrouding the camera with black cloth and having the operator stand in a position that avoids such reflections.

4.2.5   Light source amplitude variations

The light source shall be fixed-level with combined short-term and supply amplitude variations of less than ±2 %.

4.3   Temperature and relative humidity

The ambient room temperature during the acquisition of the test data shall be 23 °C ± 2 °C, as specified in ISO 554, and the relative humidity shall be 50 % ± 20 %. Additional measurements at 0 °C and 40 °C are recommended. The normal camera operating temperature (internal rise above ambient) shall be achieved before beginning the tests. If the ambient temperature varies throughout the room, for example as a result of heat generated by light sources, the ambient room temperature shall be measured at a distance of between 0,1 m and 0,2 m from the camera under test at the same height.

4.4 White balance

For a colour camera, the camera white balance shall be adjusted, if possible, to provide proper white balance (equal RGB signal levels) for the illumination light source, as specified in ISO 14524.

NOTE   In the visual noise measurement specified in Annex B, a colour cast can result in some errors being introduced into the calculation of visual noise values.

4.5 Infrared (IR) blocking filter

If required, an infrared blocking filter shall be used, as specified in ISO 14524.

4.6 Photosite integration time

The photosite integration time should not be longer than 1/30 s.

4.7 Compression

If the DSC includes any form of lossy compression, the compression shall be disabled, if possible, during the noise measurements. If the compression cannot be turned off, then measurements should be taken and the compression level reported with the noise measurement result, for example, the actual camera switch setting (fine, standard, etc.) and the approximate average number of bits per pixel.

5 Noise measurement procedures

5.1 General

These measurement procedures shall be used to determine the noise, the midtone signal-to-noise ratio, and the DSC dynamic range. The method of measuring noise on the spatially uniform field (luminance or exposure) will be dependent on the type of camera and its level of exposure automation.

On all cameras, the test chart and measurement methods described in 5.2 shall be used except in the following cases.

On cameras having manual exposure control, the measurement methods described in 5.3 shall be used when exclusion of scene dependency is required. On cameras having manual exposure control and removable lenses, the measurement methods described in 5.4 shall be used when exclusion of lens dependency, in addition to scene dependency, is required.

NOTE   Readers are referred to ISO 14524 for the details about dependency of scene and lens that characterises differences between these three measurement methods.

5.2 Measurement of a DSC using a test chart

5.2.1 General

These measurements shall be used for all cameras except in the cases when dependency of scene and/or lens is required.

5.2.2 OECF measurement

The camera opto-electronic conversion function (camera OECF) shall first be measured in accordance with ISO 14524.

5.2.3   Adjustment of illumination

For a camera that generates 8-bit per channel sRGB encoded signals, as defined in IEC 61966-2–1, the light source should be adjusted to give a pixel value equal to 118 from the background of the centre portion of the OECF test chart defined in ISO 14524. The test chart background shall be rendered to a pixel value of not less than 110 and not greater than 130.

If the camera is unable to deliver a pixel value in the range specified above, for example due to automatic exposure control, then the transmittance (or reflectance) of the central portion of the OECF may be varied. For a transmissive chart, the central portion of the chart may be replaced by a neutral density (ND) filter. For a reflective chart, an ND reflectance patch can be placed over the central portion of the chart. The transmittance (reflectance) of the filter (patch) is initially selected to approximate the transmittance (reflectance) of the chart background. If the chart background level exceeds 130, a lower density ND filter (higher reflectance patch) is selected. The automatic exposure control system of the camera will select a lower exposure level to compensate for the increase in light from the chart. This will result in a lower chart background level. Note that the chart background level is measured from the original background area of the test chart and not from the replacement ND filter. If the camera is still unable to deliver a pixel value in the specified range, then it shall be reported that the camera was unable to deliver the required test chart level and the pixel value of the chart background that was delivered shall be reported.

For a camera that generates signals in other colour encodings, the light source should be adjusted to give an output pixel value equal to the encoding values that correspond to a perceptual midtone for the background of the OECF test chart. The perceptual midtone value achieved should be reported.

NOTE   If the digital camera uses a separate camera exposure control sensor, as shown in Figure 2, an appropriate neutral density filter can be used to cover the camera exposure control sensor, in order to adjust the chart background signal to the required level.

5.2.4   Test chart

The test chart shall be a camera OECF test chart in accordance with ISO 14524. The test chart can be either transmissive or reflective (see Figure 1). The chart shall have sufficient density range so that the lightest patch is at or above the camera highlight clipping value when the test chart background is at the required encoding value. In most cases, this requires a high-contrast transparent chart and back illumination. A high-contrast transmissive 20 patch OECF test chart with a contrast ratio of 10,000:1 is recommended.

5.2.5   Non-uniformity and image structure spatial components

Non-uniformity in the test chart density patches shall be less than one tenth of the expected camera noise level, and any image structure spatial components shall be at a spatial frequency of at least 10 times higher than the camera limiting resolution. If the spatial components in the test chart have frequencies that are less than this level, then either the chart size in the image shall be decreased to achieve the required spatial frequencies, or the image of the target shall be defocused, so that the structure does not affect the noise measurement results. Test chart manufacturers shall provide information about the maximum limiting resolution a chart will support when the chart fills the camera frame.

5.2.6   Camera lens focus

The test target should be correctly focused by the camera under test. The target may be slightly out of focus, if necessary, to fulfil the requirements of 5.2.5.
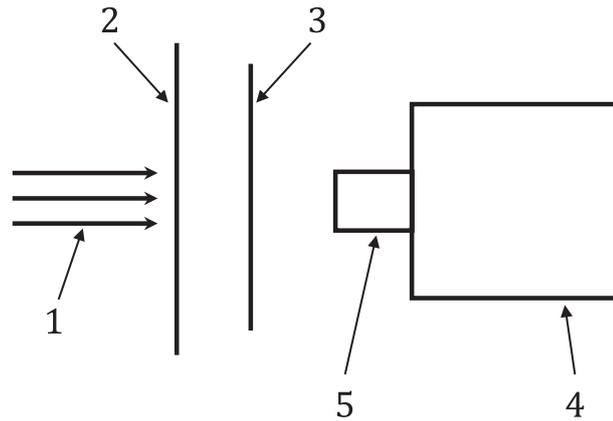
a) Test arrangement using a transmissive test chart
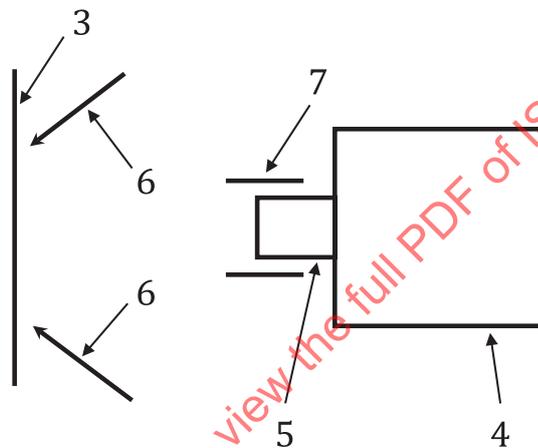
b) Test arrangement using a reflective test chart

Key

1   uniform fixed level light source
2   diffuser
3   test chart
4   camera under test
5   camera lens
6   45° uniform illumination
7   additional shielding

Figure 1 — Test chart noise measurements

5.3   Measurement of a DSC having manual exposure control

5.3.1   General

These measurements shall be used for cameras that use manual exposure control, or exposure control based on a separate exposure control sensor, when exclusion of scene dependency is required.

5.3.2   OECF measurement

The camera OECF shall be measured according to ISO 14524.

5.3.3   Adjustment of illumination

The light source and diffuser shall be adjusted to give the maximum unclipped level from the camera. If necessary, an appropriate neutral density filter should be used to cover the camera exposure control sensor in order to adjust the signal level to provide the maximum unclipped level from the camera. In some circumstances, it may not be possible to reach the maximum unclipped level due to the limitations in the resolution of the exposure adjustment or in the light source used. In this case, expose the uniform field in such a way that the exposure is increased by the smallest possible step from the exposure leading to the maximum unclipped level so that the output signal is "just clipped."

5.3.4   Test densities

A set of test densities shall be used to provide signal levels to determine the camera OECF. The densities should correspond to the densities of the patches from a test chart specified in ISO 14524. The density of the lightest patch shall provide a signal level that is at or above the maximum unclipped level from the camera. The density of the darkest patch should be greater than or equal to 2,0. If the density of the darkest patch is less than 2,0, then a test density of 2,0 density (1 % transmittance) shall be used to provide a "black reference" signal level to determine the DSC dynamic range.

Test densities shall completely cover the field of view of the camera.

5.3.5   Diffuser setting

The diffuser shall be uniform and close to the camera, preferably less than one tenth of the minimum focus distance of the camera under test, to prevent diffuser blemishes from influencing the noise measurements. The diffuser may be illuminated by either transmissive or reflective light (see Figure 2).

5.3.6   Camera lens focus

If the camera lens focus is adjustable, it shall be set to infinity.
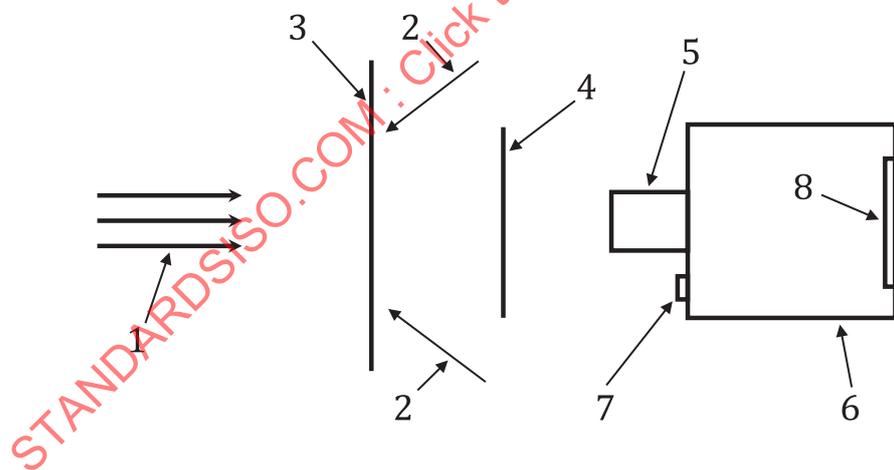
Key

1   transmissive uniform fixed level light source

2   reflective uniform fixed level light source

3   diffuser

4   test density

5   camera lens

6   camera under test

7   camera exposure control sensor

8   digital image sensor

Figure 2 — Uniform field noise measurements

5.4 Measurement of a DSC having a removable lens

5.4.1 General

This measurement shall be used for cameras having manual exposure control, or exposure control based on a separate exposure control sensor, and removable lenses, when exclusion of lens dependency, in addition to scene dependency, is required.

This method involves the exposure of the DSC sensor directly to specific quantities of uniform illumination with the lens removed. The illumination shall have the spectral characteristics specified in 4.2 and shall be produced by a small source at a distance, such that the largest dimensions of the source and the sensor are no greater than one twentieth of the distance between them, as shown in Figure 3. Reflective surfaces shall not be placed where they could cause additional illumination to be incident on the sensor.

5.4.2 OECF measurement

The focal plane opto-electronic conversion function (focal plane OECF) shall be measured in accordance with ISO 14524.

5.4.3 Adjustment of illumination

The specifications described in 5.3.3 shall be applied.

5.4.4 Test densities

The test densities specified in 5.3.4 shall be used. They shall completely cover the area exposed, when the camera lens is removed.

Key
1 light source
2 test density
3 camera under test
4 lens removed
5 digital image sensor

Figure 3 — Illumination for cameras with removable lenses

6 Calculation of metrics

6.1 General

The measurements obtained using the noise measurement procedures defined in Clause 5 are converted to reported noise values as follows:

— For the test chart case according to 5.2, a minimum of eight images shall be captured in a single session. The mean pixel value and the noise level shall be determined from an area of not less than 64 pixels × 64 pixels in the centre of each of the density patches of the test chart specified in ISO 14524.

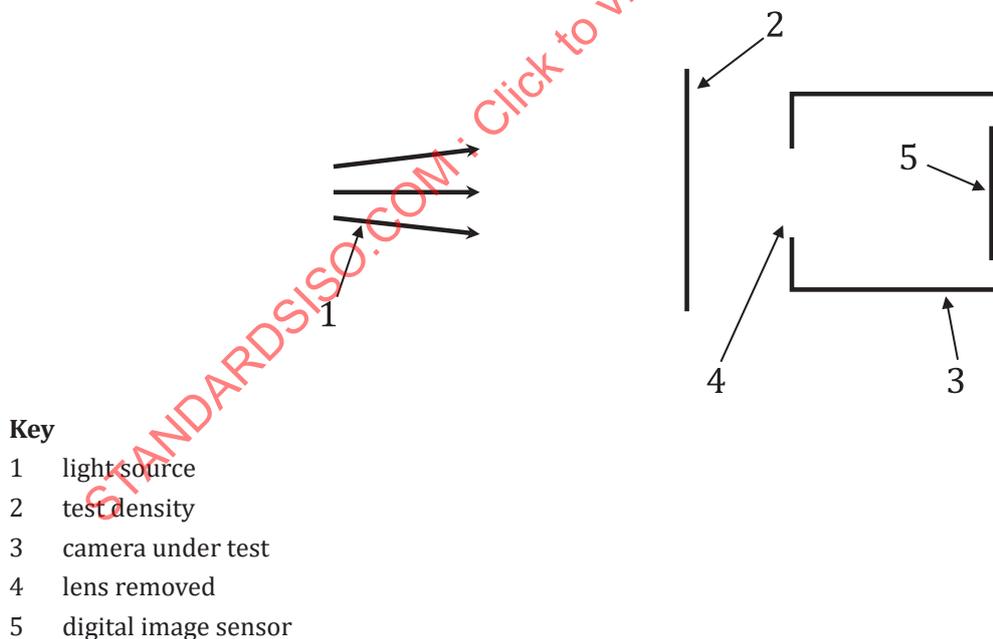— For the measurements made according to 5.3 and 5.4, a minimum of eight images shall be captured for each exposure or test density, respectively. The mean pixel value and the noise level shall be determined from an area of not less than 64 pixels × 64 pixels in the centre of each of the images.

The method for determining the noise values is specified in 6.2. An estimate of the perceived noise is computed using rms values measured in the input signals linearized from the camera output signals. The input-referred signal-to-noise ratios and the DSC dynamic range are determined using the noise values as specified in 6.3 and 6.4, respectively.

NOTE 1   The noise measurement procedures described in this document are intended to measure the temporal and fixed pattern noise standard deviations spatially over the image. They assume the temporal and spatial variations in the mean pixel values are negligible, since these variations are minimized due to the following measurement condition requirements:

a)   Frame to frame variation in mean pixel value can be introduced due to lighting flicker or changes in camera operating temperature and camera power supply. The illumination and temperature requirements specified in this document will minimize these variations.

b)   Spatial low frequency variation in mean pixel value over the patch can be introduced due to non-uniform test chart illumination and lens shading. The requirement for illumination uniformity is specified in this document and a method for removing low frequency variations from images is provided in Annex C.

NOTE 2   If it is required to include the effects of frame to frame variations in the calculation of temporal noise standard deviation then the standard deviation of individual pixel values needs to be calculated across multiple frames. In the case that temporal and/or spatial variations are required to be analysed, line/curve fitting to all pixel values of the patch across multiple frames by regression will give relevant information.

6.2 Noise

6.2.1 General

The camera noise shall be determined using the rms values measured in the input signals (luminance or exposure)[1] linearized from the camera output signals by applying the inverse OECF in accordance with ISO 14524[2]. For luminance measurement cases described in 5.2 and 5.3, the input signals are the luminance values converted using the inverse camera OECF, and the method of determining the camera noise is described in 6.2.2. For exposure measurement cases described in 5.4, the input signals are

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1)   The noise calculation procedure was revised from ISO 15739:2017 in which camera noise values were measured in camera output signals and then converted to input-referred noise values to determine signal-to-noise ratios and DSC dynamic range. In this document camera output signals are first converted to input image signals and then camera noise values are determined. The purpose of the revision was to improve measurement accuracy so that it was in accordance with ISO 12232:2019 and to revise the calculation procedure for the signal-to-noise ratios and the DSC dynamic range.

2)   The method of converting camera output signals to input signals using inverse OECF in accordance with ISO 14524, referred to as "linearization" in this document, has been used in many TC42 documents (e.g. ISO 12233).

the exposure values converted using the inverse focal plane OECF, and the method of determining the camera noise is summarized in 6.2.3.

NOTE   Linearization is used to invert recorded output signals to signals linearly proportional to scene luminance/focal plane exposure, under the assumption that the measured OECF curve approximately represents the opto-electronic conversion characteristics of the camera under test. Approximation error may be caused mainly by adaptive/local tone mapping processes during image capture.

6.2.2   Determining the noise for luminance measurements

For monochrome cameras, the camera noise, σ_{noise}, shall be determined by the luminance values linearized from monochrome output values, and shall be measured as the standard deviation of the linearized luminance values given by Formula (1):

$$\sigma_{\mathrm{noise}} = \sigma(L) \tag{1}$$

where L is the linearized luminance signal. The DSC image signals shall be linearized in accordance with ISO 14524, and the linearized luminance signal, L, shall be filtered using the filter provided in Annex C prior to determining σ_{noise} to remove low frequency variations from the image signal.

For colour cameras, the camera noise, σ_{noise}, shall be determined by the luminance values linearized from output-referred colour image signals, such as the sRGB and sYCC signals defined in IEC 61966-2-1 and Amd.1, which are used in many DSCs.

If the DSC provides output-referred sRGB colour signals, these signals shall be converted to linearized RGB signals in accordance with ISO 14524. If the DSC output signals are sYCC image signals, the signals shall be converted to sRGB image signals using IEC 61966-2-1/Amd.1. The sRGB image signals shall then be converted to linearized RGB signals in accordance with ISO 14524. If the DSC image signals are not sRGB colour signals, they shall be converted to the required signals, using an appropriate colour space conversion and rendering process if necessary, prior to performing the noise analysis.

Then, these image signals in linearized RGB, L_{R}, L_{G}, and L_{B}, are converted to image signals in Y/R-Y/ B-Y channels using Formula (2) with the weighting that shall comply with the coefficients given in ITU-R BT.709-6:

$$L_{\mathrm{Y}} = 0{,}2126 \times L_{\mathrm{R}} + 0{,}7152 \times L_{\mathrm{G}} + 0{,}0722 \times L_{\mathrm{B}} \tag{2}$$

where L_{Y} is the luminance channel signal. The value of the camera noise, σ_{noise}, shall be computed using Formula (3), as specified in ISO 12232:2019, 6.3.3, by calculating the square root of the weighted sum of the variances in Y/R-Y/B-Y channels:

$$\sigma_{\mathrm{noise}} = \sqrt{\sigma^2(L_{\mathrm{Y}}) + 0{,}279 \times \sigma^2(L_{\mathrm{R}} - L_{\mathrm{Y}}) + 0{,}088 \times \sigma^2(L_{\mathrm{B}} - L_{\mathrm{Y}})} \tag{3}$$

The linearized image signals, L_{Y}, $L_{\mathrm{R}} - L_{\mathrm{Y}}$, and $L_{\mathrm{B}} - L_{\mathrm{Y}}$, shall be filtered using the filter provided in Annex C prior to determining σ_{noise} to remove low frequency variations from the image signals.

NOTE 1   The input signals linearized from the output signals using the inverse of camera OECF are expressed as luminance values ($\mathrm{cd/m^2}$), and the rms values are calculated in these input signals for camera noise derivation. Note that applying the inverse function of $\log_{10}$ on the OECF-inverted signals is necessary to calculate the linearized input signals. In determining the signal-to-noise ratios and the DSC dynamic range, the unit is cancelled out and they are dimensionless.

NOTE 2   Formula (3) is used to obtain an estimate of the perceived noise in the image. The weights of $\sigma(L_{\mathrm{Y}})$, $\sigma(L_{\mathrm{R}} - L_{\mathrm{Y}})$, and $\sigma(L_{\mathrm{B}} - L_{\mathrm{Y}})$ were determined empirically using psychophysical experimentation and approximate the human visual system sensitivity to noise in the different channels[9].

6.2.3 Determining the noise for exposure measurements

For the case where the focal plane OECF has been measured using the method described in 5.4, the camera noise shall be determined by the exposure values linearized from camera output signals in accordance with ISO 14524. The measurement method described in 6.2.2 shall be applied.

NOTE   The input signals linearized from the output signals using the inverse of focal plane OECF are expressed as exposure values (lx·s), and the rms values are calculated in these input signals for camera noise derivation.

6.3   Signal-to-noise ratios — large area

6.3.1   General

Signal-to-noise ratio is the ratio of the input signal (luminance or exposure) level to the rms noise level at a particular signal level, and it can be measured at any signal level. In 6.3, measurement methods of signal-to-noise ratios at a particular mid-tone signal level are specified.

For the methods described in 5.2 and 5.3, the signal-to-noise ratio is determined from data captured at a luminance that is 13 % of the reference luminance. For the method described in 5.4, the signal-to-noise ratio is determined from data captured at an exposure that is 13 % of the reference exposure. In method 5.2, the signal-to-noise ratio is determined by using the density patches on the test chart specified in ISO 14524. In methods 5.3 and 5.4, the exposure and luminance are varied respectively by using the test densities specified in 5.3.4.

The total noise is converted to an input-referred signal-to-noise ratio for the density, and reported as the DSC signal-to-noise ratio.

For luminance measurement cases, the method for determining the reference luminance and the luminance value at which the signal-to-noise ratio is calculated is described in 6.3.2. The calculation procedures for the signal-to-noise ratios are described in 6.3.3, 6.3.4, and 6.3.5. For exposure measurement cases, the method for determining the reference exposure and the exposure value at which the signal-to-noise ratio is calculated, and the calculation procedures for determining the signal-to-noise ratios are summarized in 6.3.6.

6.3.2   Determining the reference luminance and luminance value for calculating signal-to-noise ratio

For the case where the camera OECF has been measured using the methods described in 5.2 and 5.3, the reference luminance shall be determined as the log luminance value corresponding to a pixel value of 245 on the camera OECF curve. This applies to camera systems that generate 8-bit sRGB signals as defined in IEC 61966-2–1. The log luminance value at the reference luminance is expressed as Formula (4):

$$S_{\text{ref}} = OECF^{-1}(I)\Big|_{I=245} \tag{4}$$

where

$\quad S_{\text{ref}}$ $\quad$ is the log luminance value at the reference luminance;

$\quad I$ $\quad$ is the pixel value;

$\quad OECF^{-1}$ $\quad$ is the inverse function of the camera OECF.

If necessary, an interpolation function may be used to determine the reference luminance value.

NOTE   A pixel value of 245 is used for determining the reference luminance instead of the maximum pixel value of 255. This is because cameras typically have a higher level of compression in their OECF curve in the region of their maximum output value and a more precise reference luminance value can be determined at a lower pixel value.

For a camera that generates images in other colour encodings, the reference luminance shall be determined as the log luminance value corresponding to a pixel value that is 91 % of the linearized camera highlight clipping value.

EXAMPLE 1   In the ROMM colour encoding space, the log luminance value is determined at the linear ROMM value equal to 91 % of 1,0 or 0,91. This corresponds to an integer value of 3886 in the 12-bit nonlinear ROMM colour space.

If the camera is a multi-spectral system, the reference luminance shall be determined from the channel with the highest signal level.

EXAMPLE 2   A camera system that creates 8-bit sRGB images is given as an example, resulting in a pixel value of 245 at input log luminance values of 2,65, 2,56, and 2,61 for the red, green, and blue channels, respectively. The reference luminance is measured from the green channel because the pixel value of the green channel reaches 245 before the red and blue channels. The reference luminance is equal to 2,56.

The total, fixed pattern, and temporal signal-to-noise ratios are specified to be measured at the luminance value that is 13 % of the luminance at the reference luminance. This can be expressed as Formula (5):

$$L_{\text{SNR}} = 0,13 \times L_{\text{ref}} \tag{5}$$

where

L_{SNR} is the luminance at which the total, fixed pattern, and temporal signal-to-noise ratios are measured;

L_{ref} is the inverse logarithm of the log luminance value at the reference luminance, S_{ref}.

Taking logarithms of both sides in Formula (5), the relationship between the log luminance values is expressed as given by Formula (6):

$$S_{\text{SNR}} = S_{\text{ref}} + \log_{10}(0,13) \tag{6}$$

where $S_{\text{SNR}} = \log_{10}(L_{\text{SNR}})$ and $S_{\text{ref}} = \log_{10}(L_{\text{ref}})$. Thus, on the camera OECF curve, the luminance at which the total, fixed pattern, and temporal signal-to-noise ratio is measured may simply be determined as the log luminance value that is $|\log_{10}(0,13)|$ below the reference luminance, S_{ref}.

6.3.3   Determining the signal-to-total noise ratio

The input-referred signal-to-total noise ratio, Q_{total}, is determined by Formula (7):

$$Q_{\text{total}} = \frac{L_{\text{SNR}}}{\sigma_{\text{total}}} \tag{7}$$

Where necessary, an interpolation function may be used to determine an accurate estimate of signal-to-total noise ratio.

The total noise is expressed using Formula (8):

$$\sigma_{\text{total}} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\sigma_{\text{total},j}^2}$$ (8)

where

σ_{total} is the standard deviation of the total noise;

$\sigma_{\text{total},j}$ is the standard deviation of the total noise in the jth image;

n is the total number of images.

$\sigma_{\text{total},j}$ is calculated as σ_{noise} using the calculation procedure in 6.2 for each image.

6.3.4 Determining the temporal signal-to-noise ratio

The temporal signal-to-noise ratio is determined by measuring the standard deviation of the difference of each image and the average image and applying a correction to estimate the true level of the temporal noise. The temporal noise is converted to an input referred signal-to-noise ratio for the density, and reported as the DSC temporal signal-to-noise ratio.

The temporal signal-to-noise ratio, Q_{temp}, is determined by Formula (9):

$$Q_{\text{temp}} = \frac{L_{\text{SNR}}}{\sigma_{\text{temp}}}$$ (9)

The temporal noise is expressed using Formula (10):

$$\sigma_{\text{temp}} = \sqrt{\frac{n}{n-1}\sigma_{\text{diff}}^2}$$ (10)

where

σ_{temp} is the standard deviation of the temporal noise;

σ_{diff} is the root mean square of the standard deviations of the pixel values of all the differences of the average and the individual images that make up the average.

Here, σ_{diff} is expressed using Formula (11):

$$\sigma_{\text{diff}} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\sigma_{\text{diff},j}^2}$$ (11)

where $\sigma_{\text{diff},j}$ is the standard deviation of the pixel values of the difference of the average image and the jth image, and is calculated as σ_{noise} using Formula (3). The average image and the difference of the average image and the jth image are calculated in Y/R-Y/B-Y image signals after conversion from linearized RGB signals of each image.

6.3.5 Determining the fixed pattern signal-to-noise ratio

The fixed pattern signal-to-noise ratio is determined by measuring the standard deviation of the average image and the standard deviation of the difference of each image and the average image. The fixed pattern noise is converted to an input-referred signal-to-noise ratio for the density, and reported as the DSC fixed pattern signal-to-noise ratio.

The DSC fixed pattern signal-to-noise ratio, Q_{fp}, is determined by Formula (12):

$$Q_{fp} = \frac{L_{SNR}}{\sigma_{fp}} \tag{12}$$

The fixed pattern noise is expressed using Formula (13):

$$\sigma_{fp} = \sqrt{\sigma_{ave}^2 - \frac{1}{n-1}\sigma_{diff}^2} \tag{13}$$

where

σ_{fp} is the standard deviation of the fixed pattern noise;

σ_{ave} is the standard deviation of the pixel values of the average of n images.

σ_{ave} is calculated as σ_{noise} using Formula (3) for the average image.

The fixed pattern noise is also expressed in Formula (14) using the total noise and the temporal noise derived by Formulae (8) and (10):

$$\sigma_{fp} = \sqrt{\sigma_{total}^2 - \sigma_{temp}^2} \tag{14}$$

The derivation of Formulae (10) and (13) shall be as shown in Annex A.

6.3.6 Determining the exposure values and the signal-to-noise ratios for exposure measurements

For the case where the focal plane OECF has been measured using the method described in 5.4, the reference exposure shall be determined as the log exposure value corresponding to a pixel value of 245 on the focal plane OECF curve. The term "luminance" shall be substituted for "exposure" and all references to camera OECF shall be replaced by focal plane OECF. The method described in 6.3.2 to 6.3.5 shall be applied to determine the exposure value for calculating the signal-to-noise ratios and to calculate the signal-to-noise ratios.

6.4 DSC dynamic range

6.4.1 General

DSC dynamic range is determined as the ratio of the input signal (luminance or exposure) saturation level to the minimum input signal level that can be captured with a signal-to-temporal noise ratio of at least 1.

The method for determining the DSC dynamic range for luminance measurement cases is described in 6.4.2, and the method for exposure measurement cases is summarized in 6.4.3.

6.4.2 Determining the DSC dynamic range for luminance measurements

For the case where the camera OECF has been measured using the methods described in 5.2 and 5.3, the DSC dynamic range is determined as the ratio of the luminance saturation level, L_{sat}, and the

minimum luminance level, L_{min}, with a signal-to-temporal noise ratio of at least 1, expressed by Formula (15):

$$\frac{L_{min}}{\sigma_{temp}} \geq 1 \tag{15}$$

The DSC dynamic range, D_R, is given by Formula (16):

$$D_R = \frac{L_{sat}}{L_{min}} \tag{16}$$

For the method in 5.2, the luminance saturation level, L_{sat}, shall be the luminance level of the patch with the lowest luminance level in the test chart, such that less than 50 % of the pixels in a uniform luminance region of interest (ROI) of the patch increase in digital value, when compared to the corresponding pixel values in the ROI of the patch in the test chart whose luminance level (density) differs by one incremental step.

The incremental step change shall increase the luminance level of the patch by no more than 26 % (0,333 step) and should increase the luminance level by no more than 10 % (0,137 step).

The test chart to be used shall be confirmed to meet this requirement for the incremental step.

EXAMPLE 1   A 20 patch OECF test chart with a contrast ratio of 10,000:1 recommended in 5.2.4, whose specification example can be derived using the parameters shown in ISO 14524:2009, Annex A, meets the requirement for the 13th to 20th patches.

The ROI shall be 64 pixels × 64 pixels, as defined in ISO 14524.

The pixel positions in the ROI of each patch shall be referenced using a relative coordinate system in which the origin of the system is situated at the same relative location in each region. The pixel values with the same relative coordinate in the ROI of two patches shall be compared.

EXAMPLE 2   A representative case is that each ROI coordinate has its origin, $x = 0$ and $y = 0$, at the top left corner pixel, and a pixel value at $x = x_0$ and $y = y_0$ of the ROI of a patch is compared to a pixel value at $x = x_0$ and $y = y_0$ of the ROI of the next patch.

Lens shading may affect the luminance saturation level determined using the test chart. If the influence of lens shading on the uniformity of pixel values in a ROI is noticeable, determining the luminance saturation level using the method 5.3 described below is recommended instead of using the method in 5.2.

NOTE   The varying effect of lens shading on pixel value uniformity of patches in the test chart may affect the accuracy of the luminance saturation level determined.

For the method in 5.3, the luminance saturation level, L_{sat}, shall be the lowest luminance level, such that less than 50 % of the pixels in a ROI increase in digital value, when the luminance level is increased by one incremental step.

The incremental step and the ROI size specified for the method in 5.2 shall be applied for the method in 5.3.

When black level clipping prevents the direct measurement of L_{min}, the minimum luminance level may be estimated by measuring the camera signal-to-temporal noise ratio using a 2,0 density "black reference" as expressed in Formula (17):

$$L_{min} = \sigma_{temp,2} \tag{17}$$

where $\sigma_{temp,2}$ is the black temporal noise measured with the density patch or the test density of 2,0 density.

The black temporal noise is derived in a similar way to the temporal noise in 6.3.4.

6.4.3   Determining the DSC dynamic range for exposure measurements

For the case where the focal plane OECF has been measured using the method described in 5.4, the DSC dynamic range is determined as the ratio of the exposure saturation level to the minimum exposure level that can be captured with a signal-to-temporal noise ratio of at least 1.

The measurement method for the method in 5.3 described in 6.4.2 shall be applied with the term "luminance" being substituted for "exposure."

NOTE   When the exposure levels are controlled by the DSC, it is preferable that the exposure level is mainly controlled by adjusting the exposure time, while the f-number of the lens and the ISO sensitivity setting of the DSC remain the same.

7   Presentation of results

7.1   General

The minimum requirement is to specify and report the midtone signal-to-total noise ratio and the DSC dynamic range of the digital camera under test. In addition, the midtone signal-to-noise ratios corresponding to the fixed pattern and temporal noise components can be expressed individually. The measurement of visual noise defined in Annex B shall not be performed and reported in place of the midtone signal-to-total noise ratio. It may, however, be performed and reported together with the midtone signal-to-total noise ratio. When it is performed, the test method and reporting of the results shall be carried out as specified in Annex B.

7.2   Signal-to-noise ratios

For luminance measurement cases, the midtone signal-to-total noise ratio is reported as a ratio determined in 6.3.3 with luminance values specified in 6.3.2. The temporal signal-to-noise ratio and the fixed pattern signal-to-noise ratio are reported as ratios determined in 6.3.4 and 6.3.5, respectively. For exposure measurement cases, these signal-to-noise ratios are determined in 6.3.6.

7.3   DSC dynamic range

The DSC dynamic range is reported as a ratio determined in 6.4.2 and 6.4.3.

In addition to reporting the DSC dynamic range as a ratio, the DSC dynamic range may also be reported as a density range or in terms of f-stops. If reported as a density range, then the DSC dynamic range is given in Formula (18):

$$D_{\mathrm{R,density}} = \log_{10}(L_{\mathrm{sat}}) - \log_{10}(L_{\mathrm{min}}) \text{ densities} \tag{18}$$

If reported in terms of f-stops, then the DSC dynamic range is given in Formula (19):

$$D_{\mathrm{R,f-stop}} = \frac{\log_{10}(L_{\mathrm{sat}}) - \log_{10}(L_{\mathrm{min}})}{\log_{10}(2,0)} \text{ f-stops} \tag{19}$$

Annex A
(normative)

Noise component analysis

A.1 Object

A.1.1 General

The object of this analysis is to show that the true levels of the noise components can be estimated from a number of samples and the average of those samples. In principle, it is possible to reduce the number of images captured to just two. However, this increases the statistical uncertainty of the noise value.

The noise in an image from a digital camera consists of a fixed pattern component and a temporally varying component. It is assumed that the two noise components are not correlated and the relationship for the total noise is as shown in Formula (A.1):

$$\sigma_{\text{total}}^2 = \sigma_{\text{fp}}^2 + \sigma_{\text{temp}}^2 \tag{A.1}$$

A.1.2 Analysis

The following notations are used for the noise component analysis:

$p_j(x,y)$	the jth uniform field digital image;
$p_{\text{fp}}(x,y)$	the fixed pattern component of the images $p_j(x,y)$;
$p_{\text{temp},j}(x,y)$	the temporally varying component of the jth image $p_j(x,y)$;
$p_{\text{ave}}(x,y)$	the average image determined from n uniform field images $p_j(x,y)$;
$\Delta p_j(x,y)$	the difference between $p_{\text{ave}}(x,y)$ and $p_j(x,y)$;
$\sigma_{\text{total},j}$	the standard deviation of $p_j(x,y)$, total noise of the jth image;
σ_{total}	the root mean square of $\sigma_{\text{total},j}$, total noise;
σ_{fp}	the standard deviation of $p_{\text{fp}}(x,y)$, fixed pattern noise;
$\sigma_{\text{temp},j}$	the standard deviation of $p_{\text{temp},j}(x,y)$, temporal noise of the jth image;
σ_{temp}	the root mean square of $\sigma_{\text{temp},j}$, temporal noise;
σ_{ave}	the standard deviation of $p_{\text{ave}}(x,y)$;
$\sigma_{\text{diff},j}$	the standard deviation of $\Delta p_j(x,y)$;
σ_{diff}	the root mean square of $\sigma_{\text{diff},j}$.

The set of n uniform field images, $p_j(x,y)$, where $x = 1 \cdots M$, $y = 1 \cdots N$, and $j = 1 \cdots n$, are captured by the camera under test and the average of these images, $p_{ave}(x,y)$, is found. The average image, $p_{ave}(x,y)$, is given by Formula (A.2):

$$p_{ave}(x,y) = \frac{1}{n} \sum_{j=1}^{n} p_j(x,y) \tag{A.2}$$

and its variance by Formula (A.3):

$$\sigma_{ave}^2 = \frac{1}{MN-1} \sum_{x,y=1}^{M,N} \left[p_{ave}(x,y) - \frac{1}{MN} \sum_{x,y=1}^{M,N} p_{ave}(x,y) \right]^2 \tag{A.3}$$

The set of n difference images, $\Delta p_j(x,y)$, $j = 1 \cdots n$, between $p_{ave}(x,y)$ and each individual image, $p_j(x,y)$, is given by Formula (A.4):

$$\Delta p_j(x,y) = p_{ave}(x,y) - p_j(x,y) \tag{A.4}$$

The variance of each difference image, $\sigma_{diff,j}^2$, is described by Formula (A.5):

$$\sigma_{diff,j}^2 = \frac{1}{MN-1} \sum_{x,y=1}^{M,N} \left[\Delta p_j(x,y) - \frac{1}{MN} \sum_{x,y=1}^{M,N} \Delta p_j(x,y) \right]^2 \tag{A.5}$$

and the average variance of the difference images, σ_{diff}^2, can be determined from $\sigma_{diff,j}^2$ as expressed by Formula (A.6):

$$\sigma_{diff}^2 = \frac{1}{n} \sum_{j=1}^{n} \sigma_{diff,j}^2 \tag{A.6}$$

Lastly, the total noise variance, $\sigma_{total,j}^2$, of the individual images, $p_j(x,y)$, is described by Formula (A.7):

$$\sigma_{total,j}^2 = \frac{1}{MN-1} \sum_{x,y=1}^{M,N} \left[p_j(x,y) - \frac{1}{MN} \sum_{x,y=1}^{M,N} p_j(x,y) \right]^2 \tag{A.7}$$

and the average total noise variance, σ_{total}^2, as given in Formula (A.8):

$$\sigma_{total}^2 = \frac{1}{n} \sum_{j=1}^{n} \sigma_{total,j}^2 \tag{A.8}$$

In the analysis that follows the fixed pattern and temporal noise standard deviations, σ_{fp} and σ_{temp}, are calculated using only σ_{ave}, σ_{diff}, and the number of uniform field digital images used, n. The analysis does not require prior knowledge of the fixed pattern and temporally varying noise components, $p_{fp}(x,y)$ and $p_{temp,j}(x,y)$.

A.1.3   Average noise

The jth uniform field image, $p_j(x,y)$, can be expressed in terms of the fixed pattern and temporally varying components, as follows in Formula (A.9):

$$p_j(x,y) = p_{fp}(x,y) + p_{temp,j}(x,y) \tag{A.9}$$

The average image of n images, p_1 to p_n, is analysed. Since the fixed pattern part of the image is, by definition, equal for all images, the pixel values of the average image are as given by Formula (A.10):

$$p_{ave}(x,y) = \frac{1}{n}\sum_{j=1}^{n} p_j(x,y) = p_{fp}(x,y) + \frac{1}{n}\sum_{j=1}^{n} p_{temp,j}(x,y) \tag{A.10}$$

The Bienaymé formula[10] states that the variance of the sum of uncorrelated random variables is equal to the sum of their variances. Since there is no correlation of the temporal noise of different images, the variance of the pixel values of the average image is given by Formula (A.11):

$$\sigma_{ave}^2 = \sigma_{fp}^2 + \frac{1}{n^2}\sum_{j=1}^{n} \sigma_{temp,j}^2 \tag{A.11}$$

Note that, when a random variable is scaled by a constant, its variance is scaled by the square of the constant. The temporal standard deviation of each image in the set of n images is assumed to be the same. If the mean of the variances of the temporal noise is denoted as σ_{temp}^2, then σ_{ave}^2 can be expressed as shown in Formula (A.12):

$$\sigma_{ave}^2 = \sigma_{fp}^2 + \frac{1}{n}\left[\frac{1}{n}\sum_{j=1}^{n} \sigma_{temp,j}^2\right] \tag{A.12}$$

$$= \sigma_{fp}^2 + \frac{1}{n}\sigma_{temp}^2$$

Thus, σ_{ave} consists of the fixed pattern noise plus an additional, residual contribution due to the temporal noise.

A.1.4 Temporal noise

The temporal noise is determined by analysing the standard deviation of the difference of each image and the average image. The pixel values of the difference images are given by Formula (A.13):

$$\Delta p_j(x,y) = \left[\frac{1}{n}\sum_{j=1}^{n} p_j(x,y)\right] - p_j(x,y) = \left[\frac{1}{n}\sum_{j=1}^{n} p_{\text{temp},j}(x,y)\right] - p_{\text{temp},j}(x,y) \tag{A.13}$$

Note that, by definition, the fixed pattern component of the noise is equal for all images, and therefore, cancels out in the expression for the difference image. The formula for the difference image can be re-written as Formula (A.14):

$$\begin{aligned}\Delta p_j(x,y) &= \frac{1}{n}\sum_{i=1,i\neq j}^{n} p_{\text{temp},i}(x,y) + \frac{1}{n}p_{\text{temp},j}(x,y) - p_{\text{temp},j}(x,y) \\ &= \frac{1}{n}\sum_{i=1,i\neq j}^{n} p_{\text{temp},i}(x,y) - \left(1-\frac{1}{n}\right)p_{\text{temp},j}(x,y)\end{aligned} \tag{A.14}$$

The variance of the pixel values of the difference image, $\sigma^2_{\text{diff},j}$, is then calculated. Using the Bienaymé formula, we can express the variance of the difference image by Formula (A.15):

$$\sigma^2_{\text{diff},j} = \frac{1}{n^2}\sum_{i=1,i\neq j}^{n} \sigma^2_{\text{temp},i} + \left(1-\frac{1}{n}\right)^2 \sigma^2_{\text{temp},j} \tag{A.15}$$

The mean of the variances of the difference images is then calculated. To do this, we first work out the sum of the variances of the difference images as follows in Formula (A.16):

$$\begin{aligned}\sum_{j=1}^{n}\sigma^2_{\text{diff},j} &= \sum_{j=1}^{n}\left(\frac{1}{n^2}\sum_{i=1,i\neq j}^{n}\sigma^2_{\text{temp},i}\right) + \sum_{j=1}^{n}\left(1-\frac{1}{n}\right)^2 \sigma^2_{\text{temp},j} \\ &= \frac{1}{n^2}\sum_{j=1}^{n}\left(\sum_{i=1,i\neq j}^{n}\sigma^2_{\text{temp},i}\right) + \left(\frac{n-1}{n}\right)^2\sum_{j=1}^{n}\sigma^2_{\text{temp},j} \\ &= \left(\frac{n-1}{n^2}\right)\sum_{j=1}^{n}\sigma^2_{\text{temp},j} + \left(\frac{n-1}{n}\right)^2\sum_{j=1}^{n}\sigma^2_{\text{temp},j} \\ &= \left(\frac{n-1}{n}\right)\sum_{j=1}^{n}\sigma^2_{\text{temp},j}\end{aligned} \tag{A.16}$$

The mean of the variances of the pixel values of the difference images is then given by Formula (A.17):

$$\sigma^2_{\text{diff}} = \frac{1}{n}\sum_{j=1}^{n}\sigma^2_{\text{diff},j} = \left(\frac{n-1}{n^2}\right)\sum_{j=1}^{n}\sigma^2_{\text{temp},j} = \left(\frac{n-1}{n}\right)\sigma^2_{\text{temp}} \tag{A.17}$$

The standard deviation of the temporal noise is thus given by Formula (A.18):

$$\sigma_{\text{temp}} = \sqrt{\frac{n}{n-1}\sigma^2_{\text{diff}}} \tag{A.18}$$

Note that σ^2_{temp} is not equal to the mean of the variances of the difference images and the factor $n/(n-1)$ takes into account the lack of correlation between the images mentioned above.

A.1.5 Fixed pattern noise

Substituting the expressions for σ_{diff}^2 and σ_{temp}^2 in Formula (A.12) the value for σ_{ave}^2 can be re-expressed as given by Formula (A.19):

$$\sigma_{ave}^2 = \sigma_{fp}^2 + \frac{1}{n-1}\sigma_{diff}^2 \tag{A.19}$$

Using this result, the standard deviation of the fixed pattern noise can be obtained as given by Formula (A.20):

$$\sigma_{fp} = \sqrt{\sigma_{ave}^2 - \frac{1}{n-1}\sigma_{diff}^2} \tag{A.20}$$

NOTE   If the fixed pattern noise standard deviation is much smaller than the temporal noise standard deviation, it may be possible, with a small number of samples that the sample uncertainty results in the fixed pattern noise being the square root of zero or a negative number. The solution is to increase the number of samples.

A.2 Method using eight images

A.2.1 Step-by-step description

a)   First all the images are linearized.

b)   The second step is to calculate the average image and evaluate the standard deviation of the average image, σ_{ave}.

c)   The third step is to calculate the difference of each image and the average image.

d)   The fourth step is to calculate the standard deviations of the pixel values of the difference images to give $\sigma_{diff,j}$, where j = 1 to 8.

e)   The fifth step is to calculate the mean of all squared standard deviations of the difference images by Formula (A.21):

$$\sigma_{diff}^2 = \frac{1}{8}\sum_{j=1}^{8}\sigma_{diff,j}^2 \tag{A.21}$$

f)   The standard deviation of the temporal noise is then calculated by Formula (A.22):

$$\sigma_{temp} = \sqrt{\frac{8}{7}\sigma_{diff}^2} \tag{A.22}$$

g)   The standard deviation of the fixed pattern noise is calculated by Formula (A.23):

$$\sigma_{fp} = \sqrt{\sigma_{ave}^2 - \frac{1}{7}\sigma_{diff}^2} \tag{A.23}$$

A.2.2 Evaluation of the method using example data

A.2.2.1 Example data

Table A.1 shows an example of the mean pixel values of eight images, example standard deviation values, $\sigma_{total,j}$, for each image, and the standard deviation of the pixel values of the difference of each of the eight images and the average image. Note that the method described in this example also applies to a region from an image of an OECF test target corresponding to a single patch on the target.

Table A.1 — Example noise data for eight images

Dimensions in cd/m^2

Image j	Mean pixel value	$\sigma_{\text{total},j}$	$\sigma_{\text{diff},j}$
1	91,27	2,17	1,91
2	91,04	2,18	1,92
3	91,05	2,10	1,87
4	90,96	2,14	1,89
5	90,95	2,12	1,89
6	90,89	2,13	1,92
7	91,10	2,12	1,91
8	91,13	2,19	1,93

A.2.2.2 Evaluation

Step 1   The mean pixel value of the average image is 91,05 (from Table A.1) and the standard deviation of the pixel values of the average of the eight images is given as 1,01, i.e. σ_{ave} = 1,01.

Step 2 to 4   The mean of the squared standard deviations of the eight difference images is 3,63 (from Table A.1), i.e. σ_{diff}^2 = 3,63.

Step 5   Formula (A.22) yields 2,04 for the standard deviation of the temporal noise, i.e. σ_{temp} = 2,04.

Step 6   The standard deviation of the fixed pattern noise can be calculated according to Formula (A.23), σ_{fp} = 0,71.

The result of the calculation can be verified by checking that the squared sum of the temporal and the fixed pattern noise results in the total noise shown in Table A.1.

The square root of the sum of the squares of the temporal and fixed pattern noise is 2,16 and the square root of the average of the squares of the total noise from Table A.1 is 2,14.

Annex B
(normative)

Visual noise measurements

B.1 General

This annex provides a method for measuring the visual noise level[3),4)] that is based on the algorithm for measuring scanner noise described in References [11][12]. The visual noise is evaluated as an output referred noise, unlike the camera noise described in 6.2 used for determining signal-to-noise ratios and DSC dynamic range. The general steps of the method are given below.

a) An image of the OECF target is taken as described in 5.2.

b) The RGB image is converted into the opposite colour components white-black, red-green, and yellow-blue via *XYZ*.

c) Visual noise level measurements are designed to correlate well with the visual appearance of noise in images, so it is appropriate to measure images that represent the intended colour appearance on some specified reference medium, and for some specified reference viewing conditions. The specific method provided in this annex measures the visual noise level of images encoded using the sRGB colour encoding defined in IEC 61966-2–1.

> NOTE   Images in other colour encodings can usually be converted to sRGB, for example using ICC colour management as defined in ISO 15076-1. If the reference medium and viewing conditions for other encodings are very different from the sRGB reference display and viewing conditions, the visual noise measurements obtained by converting to sRGB and applying the method in this annex will not necessarily correlate with the visual appearance of noise in the original images.

d) The image data of each density patch is converted to the spatial frequency domain using the discrete Fourier transform.

e) The noise spectra are weighted using the contrast sensitivity functions (CSF) of the human eye at a specific viewing angle with respect to the image height. The weighted spectra are converted back to the spatial domain using the inverse discrete Fourier transform.

f) The image is then converted back into *XYZ* and from there into the uniform *L*a*b** colour space, defined by the CIE[7].

g) The square root of the weighted sum of the three filtered noise variances for each axis are calculated.

The flow diagram in Figure B.1 shows a high level comparison between the processing in the human visual system and the visual noise algorithm.

---

3)   The method of measuring the visual noise level was revised[17][18] from ISO 15739:2017: a) CSF was changed avoiding *XYZ* calculation being out of its range; b) Colour space for measuring visual noise was changed from *L*u*v** to *L*a*b** because of having better perceptual uniformity for larger colour differences assumed for higher ISO sensitivity settings, being more robust in calculation at very dark colours, and being more commonly used in imaging industry; c) Visual noise calculation formula was changed from the weighted sum of the standard deviations to the square root of the weighted sum of the variances, and the weighting coefficients were adjusted, to match the human visual system more closely.

4) Visual noise level measured using the method specified in this document is three to five times smaller than visual noise level measured for the same image using the method specified in ISO 15739:2017. Attention is drawn to this difference in referring to measured visual noise data.

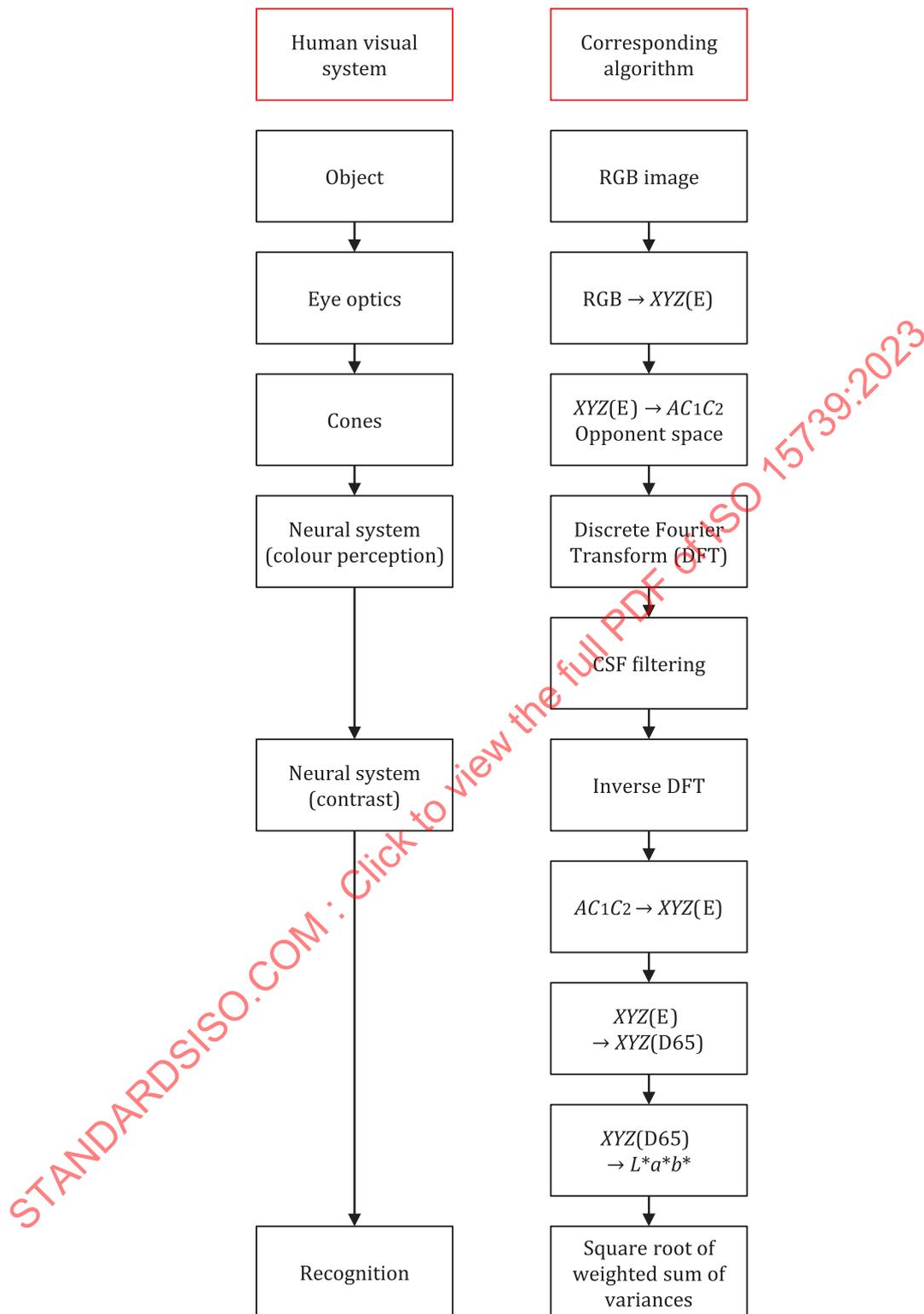| Human visual system		Corresponding algorithm
Object		RGB image
Eye optics		RGB → XYZ(E)
Cones		XYZ(E) → AC_1C_2 Opponent space
Neural system (colour perception)		Discrete Fourier Transform (DFT)
		CSF filtering
Neural system (contrast)		Inverse DFT
		AC_1C_2 → XYZ(E)
		XYZ(E) → XYZ(D65)
		XYZ(D65) → $L^*a^*b^*$
Recognition		Square root of weighted sum of variances

Figure B.1 — Human visual system and corresponding visual noise algorithm

B.2 Algorithm used for the visual noise measurements

B.2.1 RGB to *XYZ*(E)

The R, G, and B signals are as defined in the sRGB standard IEC 61966-2–1. The R, G, and B pixel values of the image are linearized using the sRGB characterization Formula (B.1), as originally defined in IEC 61966-2–1:1999, Formulae (4), (5), and (6).

$$C_l = C_n / 12{,}92 \qquad \text{for } C_n \leq 0{,}040\ 45$$

$$C_l = [(C_n + 0{,}055)/1{,}055]^{2,4} \qquad \text{for } C_n > 0{,}040\ 45 \tag{B.1}$$

$$C_n = C_c / C_m$$

where

C_c is the R, G, and B sRGB image pixel values;

C_m is the maximum sRGB pixel value, e.g. 255 for 8-bit per component sRGB;

C_n is the normalized nonlinear R, G, and B sRGB values;

C_l is the normalized linearized R, G, and B sRGB values.

These linearized sRGB values are converted to the normalized *XYZ*(D65) values using Formula (B.2), as originally defined in IEC 61966-2–1:1999, Formula (7).

$$\begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} = \begin{bmatrix} 0{,}412\ 4 & 0{,}357\ 6 & 0{,}180\ 5 \\ 0{,}212\ 6 & 0{,}715\ 2 & 0{,}072\ 2 \\ 0{,}019\ 3 & 0{,}119\ 2 & 0{,}950\ 5 \end{bmatrix} \cdot \begin{bmatrix} R_{sRGB} \\ G_{sRGB} \\ B_{sRGB} \end{bmatrix} \tag{B.2}$$

The veiling glare (0,2 cd/m²) defined in IEC 61966-2–1 for the reference viewing condition is added and re-normalized with the display white point luminance (80 cd/m²). These values are then converted to *XYZ*(E) using Formula (B.3). A chromatic adaptation transform (CAT) matrix to convert *XYZ* values from illuminant D65 to E using the linearized Bradford transformation is derived.

$$\begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix} = \begin{bmatrix} 1{,}050\ 30 & 0{,}027\ 10 & -0{,}023\ 29 \\ 0{,}039\ 09 & 0{,}972\ 94 & -0{,}009\ 27 \\ -0{,}002\ 41 & 0{,}002\ 66 & 0{,}917\ 89 \end{bmatrix} \cdot \frac{1}{(80+0{,}2)} \left\{ 80 \begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} + 0{,}2 \begin{bmatrix} 0{,}950\ 4 \\ 1{,}000\ 0 \\ 1{,}088\ 9 \end{bmatrix} \right\} \tag{B.3}$$

The linearized Bradford matrix used to derive the CAT matrix is given in Formula (B.4):

$$M_{BFD} = \begin{bmatrix} 0{,}895\ 1 & 0{,}266\ 4 & -0{,}161\ 4 \\ -0{,}750\ 2 & 1{,}713\ 5 & 0{,}036\ 7 \\ 0{,}038\ 9 & -0{,}068\ 5 & 1{,}029\ 6 \end{bmatrix} \tag{B.4}$$

NOTE 1   The D65 chromaticity for the veiling glare term in Formula (B.3) is chosen for simplicity. A different chromaticity can be used for the veiling glare if desired.

NOTE 2   If the image data are not in the sRGB colour encoding space and an ICC profile is present, then the image data is converted directly into *XYZ*(E) values without first converting the data to sRGB.

B.2.2 *XYZ*(E) into opponent space AC_1C_2

The tristimulus values, X_E, Y_E, and Z_E, are transferred into the opponent space, A, C_1, and C_2, using the matrix given by Formula (B.5):

$$\begin{bmatrix} A \\ C_1 \\ C_2 \end{bmatrix} = \begin{bmatrix} 0 & 1,0 & 0 \\ 1,0 & -1,0 & 0 \\ 0 & 0,4 & -0,4 \end{bmatrix} \cdot \begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix} \tag{B.5}$$

The opponent colour space, A, C_1, and C_2, is described in Reference [11].

B.2.3 Discrete Fourier transform (DFT)

Using the discrete Fourier transform, the set of opponent responses, A, C_1, and C_2, is transferred from the spatial domain into the frequency domain, $\hat{A}$, $\hat{C}_1$, and $\hat{C}_2$.

$$A \xrightarrow{\text{DFT}} \hat{A}$$
$$C_1 \xrightarrow{\text{DFT}} \hat{C}_1 \tag{B.6}$$
$$C_2 \xrightarrow{\text{DFT}} \hat{C}_2$$

NOTE   The units of frequency are cycles per pixel.

B.2.4 Applying the contrast sensitivity function

In the frequency domain, each response is weighted by a set of corresponding spatial responses of the human visual system. There are many aspects that affect the contrast sensitivity of the human eye. It is necessary, therefore, to select a set that is representative of typical viewing conditions. A set of contrast sensitivity functions closely based on the CSF functions specified in Reference [13] was selected for this document. The CSF used for the luminance channel is based on the work of Movshon and the CSF used for the chrominance channels is modelled on data sets provided by Van der Horst and Poirson.

The function used to model the CSF for the luminance channel, A, is given by:

$$W_{\text{lum}}(f) = 1 \qquad \text{for } f = 0$$
$$W_{\text{lum}}(f) = \frac{\left(a \cdot f^c\right) \cdot e^{-bf}}{K} \qquad \text{for } f > 0 \tag{B.7}$$

where the variables used are given in Table B.1:

Table B.1 — Variables used for the luminance CSF function

Luminance channel (A) variables	
a	75
b	0,2
c	0,8
K	102,16

The frequency, f, is specified in units of cycles per degree of visual angle.

NOTE 1   The luminance contrast sensitivity function described by Formula (B.7) is suited primarily to DSCs that introduce low levels of image noise into the captured image.

NOTE 2   The value of the CSF for the luminance channel is defined to be 1 at $f = 0$ so that the average luminance value before Fourier transform and the average luminance value after CSF application and inverse Fourier transform are to be the same.

The function used to model the CSF for the chrominance channels, C_1 and C_2, is given by:

$$W_{\text{chrom}}(f) = \frac{a_1 \cdot e^{-b_1 f^{c_1}} + a_2 \cdot e^{-b_2 f^{c_2}} - S}{K}$$

(B.8)

where the variables used are given in Table B.2.

Table B.2 — Variables used for the chrominance channel CSF function

Chrominance variables	C_1	C_2
a_1	109,141 3	7,032 8
b_1	0,000 4	0
c_1	3,424 4	4,258 2
a_2	93,597 1	40,691
b_2	0,003 7	0,103 9
c_2	2,167 7	1,648 7
K	202,738 4	40,691
S	0	7,032 8

The contrast sensitivity functions are shown plotted in Figure B.2.
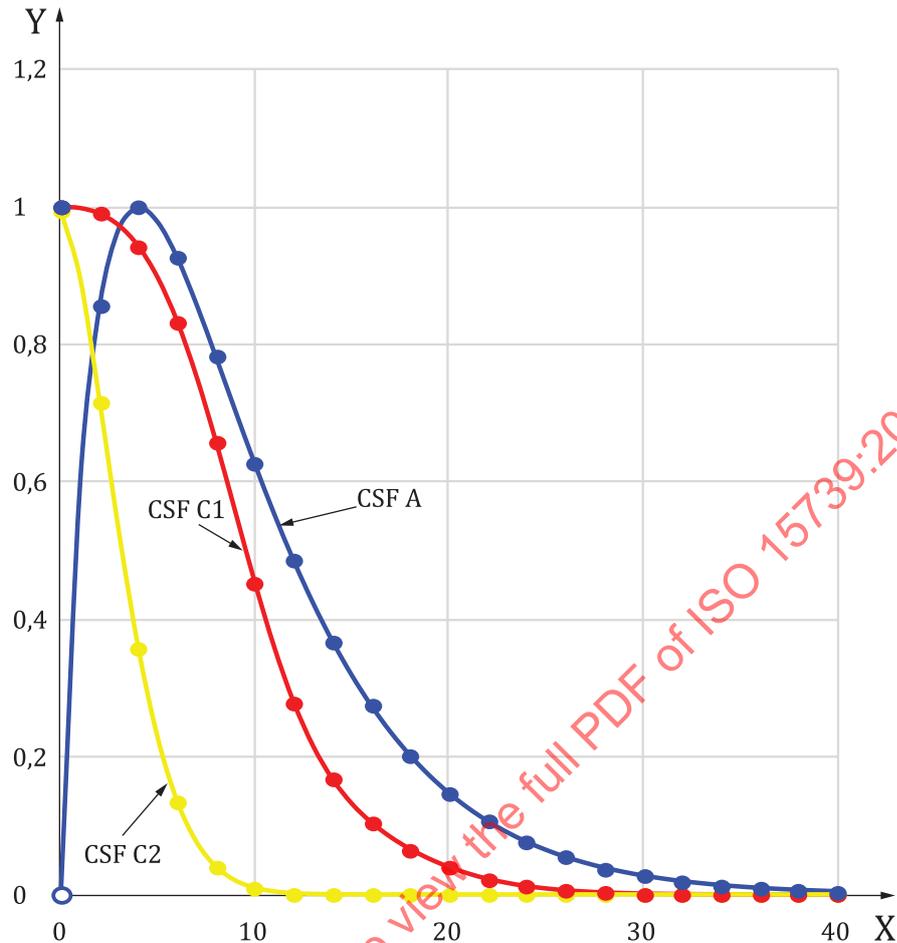
Key

X frequency (cycles/degree)

Y sensitivity

Figure B.2 — Contrast sensitivity functions of the human eye used in ISO 15739

Before applying the CSF models to the frequency data computed in B.2.3, the data need to be first converted from units of cycles per pixel to the units of cycles per degree of visual angle. The maximum frequency that can be represented in an image, according to Nyquist, is 0,5 cycles per pixel. In order to convert the frequency in cycles per pixel into the cycles per degree that is used for the contrast sensitivity of the human eye, we need to know the size of each pixel (pixel pitch) in the final picture viewed by the observer and the viewing distance. The viewing angle, α, subtended by one pixel pitch is given by:

$$\tan(\alpha) = \frac{P}{D} \Rightarrow \alpha = \frac{180°}{\pi} \arctan\left(\frac{P}{D}\right) \tag{B.9}$$

where

P is the pixel pitch;

D is the viewing distance.

The frequency in cycles per degree is given as:

$$f_{\left[\frac{\text{cycles}}{\text{degree}}\right]} = f_{\left[\frac{\text{cycles}}{\text{pixel}}\right]} \cdot \frac{1}{\alpha} \tag{B.10}$$

The image is then filtered using:

$$\begin{aligned}
\hat{A}_{\text{f}} &= \hat{A} W_{\text{A}} \\
\hat{C}_{1,\text{f}} &= \hat{C}_1 W_{\text{C},1} \\
\hat{C}_{2,\text{f}} &= \hat{C}_2 W_{\text{C},2}
\end{aligned} \tag{B.11}$$

where W_{A}, $W_{\text{C},1}$, and $W_{\text{C},2}$ are circularly symmetric two-dimensional CSFs generated from the corresponding one-dimensional CSFs. W_{A} corresponds to the CSF given in Formula (B.7) with the coefficients in Table B.1. $W_{\text{C},1}$ and $W_{\text{C},2}$ correspond to the CSFs given in Formula (B.8) with the coefficients for C_1 and C_2, respectively, in Table B.2.

B.2.5 Inverse Fourier transform

Each compensated response is transferred into the spatial domain by the inverse discrete Fourier transform. This is expressed as:

$$\begin{aligned}
\hat{A}_{\text{f}} &\xrightarrow{\text{inverse DFT}} A_{\text{f}} \\
\hat{C}_{1,\text{f}} &\xrightarrow{\text{inverse DFT}} C_{1,\text{f}} \\
\hat{C}_{2,\text{f}} &\xrightarrow{\text{inverse DFT}} C_{2,\text{f}}
\end{aligned} \tag{B.12}$$

NOTE   The output of the inverse discrete Fourier transform contains only real values and does not contain complex values.

B.2.6 Opponent space AC_1C_2 into XYZ(E)

The three opponent colour responses, A_{f}, $C_{1,\text{f}}$, and $C_{2,\text{f}}$, are transferred into tristimulus values, X_{E}, Y_{E}, and Z_{E}, using a matrix equal to the inverse of Formula (B.5). The matrix is given as:

$$\begin{bmatrix} X_{\text{E}} \\ Y_{\text{E}} \\ Z_{\text{E}} \end{bmatrix} = \begin{bmatrix} 1{,}0 & 1{,}0 & 0 \\ 1{,}0 & 0 & 0 \\ 1{,}0 & 0 & -2{,}5 \end{bmatrix} \cdot \begin{bmatrix} A_{\text{f}} \\ C_{1,\text{f}} \\ C_{2,\text{f}} \end{bmatrix} \tag{B.13}$$

B.2.7 XYZ(E) to XYZ(D65)

The values X_{E}, Y_{E}, and Z_{E}, are transferred into the tristimulus values, X_{D65}, Y_{D65}, and Z_{D65}, using a matrix equal to the inverse of the matrix in Formula (B.3). The matrix is given as:

$$\begin{bmatrix} X_{\text{D65}} \\ Y_{\text{D65}} \\ Z_{\text{D65}} \end{bmatrix} = \begin{bmatrix} 0{,}953\ 15 & -0{,}026\ 61 & 0{,}023\ 92 \\ -0{,}038\ 27 & 1{,}028\ 85 & 0{,}009\ 42 \\ 0{,}002\ 61 & -0{,}003\ 05 & 1{,}089\ 49 \end{bmatrix} \cdot \begin{bmatrix} X_{\text{E}} \\ Y_{\text{E}} \\ Z_{\text{E}} \end{bmatrix} \tag{B.14}$$

If any tristimulus values are negative, then they are clipped to be zero.

B.2.8 XYZ(D65) to $L^*a^*b^*$

The tristimulus values are converted into the CIE $L^*a^*b^*$ colour space as follows:

$$L^* = 116 f\left(\frac{Y}{Y_{\text{n}}}\right) - 16 \tag{B.15}$$

$$a^* = 500 \left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right) \right]$$

$$b^* = 200 \left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right) \right]$$

(B.16)

where

$$f(s) = \sqrt[3]{s} \qquad \text{for } s > 0{,}008\ 856$$

$$f(s) = 7{,}787 \times s + \frac{16}{116} \quad \text{for } s \leq 0{,}008\ 856$$

and for the D65 white-point:

$$X_n = 0{,}950\ 5$$

$$Y_n = 1{,}00$$

(B.17)

$$Z_n = 1{,}089\ 1$$

B.2.9 Determining the standard deviation for each grey patch

The standard deviations of the colour noise along the three axes of the uniform colour space, L^*, a^*, and b^*, are given as:

$$\sigma_{L^*} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_{L^*_i} - \overline{x_{L^*}})^2}$$

$$\sigma_{a^*} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_{a^*_i} - \overline{x_{a^*}})^2}$$

(B.18)

$$\sigma_{b^*} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_{b^*_i} - \overline{x_{b^*}})^2}$$

where N is equal to the number of evaluated pixels in the patch. The requirement for N is specified in B.3.1.

B.2.10 The weighted sum representing the visual noise

The visual noise is defined as the square root of the weighted sum of the three colour noise variances along the L^*, a^* and b^* axes. The formula to determine the visual noise value is as follows:

$$V = \sqrt{\sigma_{L^*}^2 + (0{,}338 \times \sigma_{a^*})^2 + (0{,}395 \times \sigma_{b^*})^2}$$

(B.19)

NOTE 1   The weighting coefficients in Formula (B.19) are used to derive visual noise values combining rms values in L^*, a^*, and b^* colour channels. These were determined empirically using psychophysical experimentation and represent the human visual system sensitivity to noise in the different channels, in combination with CSF characteristics for the three channels, in the whole visual noise calculation process. Although σ_{b^*} is more weighted than σ_{a^*} in Formula (B.19), the noise along the yellow-blue axis is less weighted than the noise along the red-green axis in the overall calculation of visual noise. This is because the effective bandwidth of the CSF in the C_2 channel is much narrower than in the C_1 channel as shown in Figure (B.2).

NOTE 2   See Footnote 4) in B.1 regarding differences between the measured visual noise levels using the method described in this document and the measurements obtained using the method specified in ISO 15739:2017.

NOTE 3   Readers are referred to Annex F for the informative introduction of perceptually uniform mapping of visual noise to noisiness JND.

NOTE 4   There is ongoing research[19][20] that is investigating the dependency of perceived noise levels on variations in the luminance level of images displayed on a monitor.

B.3   Visual noise measurements

B.3.1   Test conditions

The test chart and the capturing conditions shall comply with 5.2. A high contrast back illuminated transmissive 20 patch OECF test chart with a contrast ratio of 10,000:1 is recommended.

In determining the standard deviation for each grey patch described in B.2.9, the number of pixels, N, shall be equal to or greater than 64.

B.3.2   Evaluation of visual noise

The test image shall be in the sRGB colour encoding space or with an ICC profile. The visual noise value shall be calculated in accordance with B.2.

NOTE   Source code created using Matlab®[5] that performs the visual noise measurement algorithm specified in this document can be accessed from www.iso.org/15739.

B.4   Reporting the results

The visual noise shall be reported in a table where the first column is the average sRGB pixel value for each patch of the OECF chart, the second column is the L^* value corresponding to the average pixel value as computed using Formulae (B.1), (B.2), (B.3), (B.14), and (B.15), and the third column is the visual noise level for that patch. If the original input image is in a colour encoding space other than sRGB [see note in (B.1 c)], then the average pixel values for each patch in the original image shall be included in the first column of the table. In this case, the converted average sRGB pixel value, the L^* value and the visual noise level for that patch shall be reported in the second, third, and fourth columns of the table.

In addition, the maximum sRGB pixel value, the viewing distance and the size of the output pixel shall be reported. The output image height and the pixel count for the image height may be reported in place of the pixel size. A sample evaluation of the visual noise for an sRGB image is shown in Table B.3.

When reporting the measurement method the edition of ISO 15739 that was used should be specified. In the case that visual noise values are reported, together with visual noise values using the method specified in a previous edition of ISO 15739, the report shall clarify from which edition the visual noise values are calculated e.g., by using symbols V_{ed4}, V_{ed3}, etc.

Table B.3 — Example visual noise data

Average sRGB pixel value C	Lightness L^*	Visual noise level V
1,3	11,2	0,3
2,4	11,4	0,3
5,8	12,1	0,5
12,4	13,4	0,6
28,0	17,6	1,5
53,5	26,6	2,4

5)   Matlab is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

Table B.3 *(continued)*

Average sRGB pixel value C	Lightness L*	Visual noise level V
76,3	35,3	2,6
93,2	41,8	2,7
116,0	50,5	2,6
135,3	57,7	2,3
160,0	66,8	2,4
173,7	71,7	2,1
196,4	79,9	1,8
209,3	84,4	1,6
223,8	89,4	1,2
233,7	92,8	1,1
245,3	96,7	0,6
252,8	99,2	0,3
255,0	100,0	0
255,0	100,0	0
Maximum sRGB pixel value = 255		
Viewing distance = 1 000 mm		
Size of output pixel = 0,266 mm		

Annex C
(normative)

Removing low frequency variations from the image signals

C.1 General

Many DSCs exhibit lens shading, which is characterised by a slowly varying centre to edge intensity roll off. Non-uniform test chart illumination can also introduce low frequency variations in the captured image. These non-uniformities shall be removed from the image signals before measuring the noise, since they degrade (increase) the measured noise standard deviations.

The 13 × 13 tap FIR high-pass filter specified in this annex shall be used to be convolved with the linearized image signals, L_Y, $L_R - L_Y$, and $L_B - L_Y$, to remove the low frequency variations from the image signals. The spatial frequency response of this FIR filter greatly attenuates the lowest image spatial frequencies, including the non-uniformities described above.

The high-pass filter shall be applied only to the evaluation of the total, fixed pattern, and temporal signal-to-noise ratio. It should not be applied to visual noise measurements. This is because at high image resolutions, the filter will affect the range of frequencies in the region of the peak of the luminance contrast sensitivity function given in B.2.4. Alternative methods for removing low frequency variations such as compensation by capturing a uniform white board should be considered.

C.2 Application of the high-pass filter

The 13 × 13 tap high-pass FIR filter shall be applied to the linearized image signals, L_Y, $L_R - L_Y$, and $L_B - L_Y$, prior to computing σ_{noise}. Table C.1 displays the bottom-right quadrant of the 13 × 13 kernel that shall be used. The whole 13 × 13 kernel is defined by reflecting the bottom six rows about the first row, and then reflecting that result about the first column. Since the table values are redundant and symmetric, only the bottom right quadrant is specified here. Negative filter output values shall not be clipped to zero prior to computing σ_{noise}.

NOTE   The 13 × 13 FIR filter removes the DC component of the image, and thus, the mean signal value cannot be computed from the filter output values.

Table C.1 — High-pass filter kernel (lower right quadrant)

0,996 926	−0,006 47	−0,007 4	−0,006 09	−0,009 6	−0,003 82	−0,009 64
−0,006 47	−0,006 64	−0,012 23	−0,005 8	−0,007 3	−0,005 48	−0,008 93
−0,007 4	−0,012 23	−0,001 73	−0,009 89	−0,005 71	−0,007 06	−0,007 18
−0,006 09	−0,005 8	−0,009 89	−0,007 92	−0,003 56	−0,009 76	−0,003 59
−0,009 6	−0,007 3	−0,005 71	−0,003 56	−0,009 64	−0,006 54	0,000 124
−0,003 82	−0,005 48	−0,007 06	−0,009 76	−0,006 54	−0,000 44	0,000 412
−0,009 64	−0,008 93	−0,007 18	−0,003 59	0,000 124	0,000 412	−0,000 13