BS ISO 15739:2013

BSI Standards Publication

Photography — Electronic still-picture imaging — Noise measurements

National foreword

This British Standard is the UK implementation of ISO 15739:2013. It supersedes BS ISO 15739:2003 which is withdrawn.

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

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

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ISBN 978 0 580 76903 0

ICS 37.040.99

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 June 2013.

Amendments issued since publication

Date	Text affected

INTERNATIONAL STANDARD

ISO 15739

Second edition
2013-06-15

Photography — Electronic still-picture imaging — Noise measurements

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

Reference number
ISO 15739:2013(E)

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Foreword

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

The committee responsible for this document is ISO/TC 42, *Photography*.

This second edition cancels and replaces the first edition (ISO 15739:2003), which has been technically revised.

Introduction

Noise is an important attribute of electronic photographic systems. The camera noise measurements described in this International Standard are performed in the digital domain, using digital analysis techniques. Since the noise performance of an image sensor may vary significantly with exposure time and operating temperature, these operating conditions are specified. 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 magnitude of the noise present in an output representation depends on the noise present in the stored image data and the contrast amplification or gain applied to the data in producing the output. The noise visibility is different for the luminance (or monochrome) channel and the colour (or colour difference) channels. Therefore, this International Standard accounts for these factors in measuring and reporting the camera noise measurements. Annex A specifies the method for determining the components of the digital camera noise from a number of samples. The perceptibility of noise in an image can vary depending on the viewing distance, spatial frequency, density, colour and viewing conditions. Annex B describes a procedure for measuring the visual noise level using a human visual model as a method for weighting the spectral components of the noise. A method for removing low frequency variations in the patch data resulting, for example, from luminance shading is given in Annex C. A recommended step-by-step procedure for determining the signal to noise ratio and incremental gain is provided in Annex D. In Annex E recommendations for practical viewing conditions for various output media are given.

Photography — Electronic still-picture imaging — Noise measurements

1 Scope

This International Standard 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, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 12232:2006, *Photography — Digital still cameras — Determination of exposure index, ISO speed ratings, standard output sensitivity, and recommended exposure index*

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

ITU-R BT.709-5, *Parameter values for the HDTV Standards for production and International programme exchange*

CIE 15:2004, *Colorimetry*, 3rd edition

3 Terms and definitions

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

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

Note 1 to entry: The units of measurement for this function are $\log_{10}$ candelas per square metre.

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

Note 1 to entry: A charge coupled device (CCD) array is an example of an image sensor.

3.5
incremental gain function
incremental gain
change in the pixel values of the DSC divided by the change in the exposure values

Note 1 to entry: For the determination of incremental gain values, log input values are not used.

Note 2 to entry: If the input exposure points are very finely spaced and the output noise is small compared to the quantization interval, the incremental gain function can have a jagged shape. Such behaviour is an artefact of the quantization process and is removed by using an appropriate smoothing algorithm, or by fitting a smooth curve to the data. In some cases, it may be desirable to fit a curve to the input-output data and then determine the incremental gain function by taking the first derivative of the function used for the curve fit.

3.6
incremental output signal
exposure level multiplied by the incremental gain at that particular exposure level

3.7
incremental signal-to-noise ratio
ratio of the incremental output signal to the root mean square (rms) noise level, at a particular signal level

Note 1 to entry: This is typically expressed as a graph or Table showing the incremental signal-to-noise ratio versus input signal level for the full range of input signal levels.

3.8
DSC dynamic range
ratio of the maximum exposure level that provides a pixel value below the highlight clipping value to the minimum exposure level that can be captured with an incremental signal-to-temporal-noise ratio of at least 1, as determined in accordance with ISO 15739

3.9
noise
unwanted variations in the response of an imaging system

3.9.1
total noise
all the unwanted variations, consisting of pattern noise and temporal noise, of the values in the digitized output captured by a single exposure

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

3.9.2
fixed pattern noise
unwanted variations of the values in the digitized output which remain constant between exposures

3.9.3
temporally varying noise
unwanted variation in the values of the digitized output that changes from one exposure to the next due to sensor dark current, photon shot noise, analogue processing and quantization

3.10
noise spectrum
curve or equation which expresses the image noise as a function of two-dimensional image spatial frequencies

3.11
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 units of measurement for this function are $\log_{10}$ lux seconds.

3.12
exposure time
total time period during which the photo sensor is able to integrate the light from the scene to form an image

3.13
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 Table 1 of ISO 7589:2002 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 Table 2 of ISO 7589:2002 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 14524:2009.

NOTE In particular, if a transmissive chart is used, light from the chart may 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.

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 Colour noise weighting

For colour cameras using a single exposure process, the camera noise may be determined using a weighted sum of the colour outputs to derive the luminance. If the proper luminance weighting values for the RGB channel spectral sensitivities are known, they shall be used to calculate the luminance channel data. If these values are not known, the following weighting, given in ITU-R BT.709, shall be used:

$$Y = 0{,}2125\ R + 0{,}7154\ G + 0{,}0721\ B \tag{1}$$

For colour cameras with luminance and colour-difference outputs, the standard deviation of the camera noise may be computed from the luminance channel standard deviation σ (Y), the red minus luminance channel standard deviation σ (R-Y) and the blue minus luminance channel standard deviation σ (B-Y). The following Formula (2), as specified in 6.3.3 of ISO 12232:2006 shall be used:

$$\sigma(D) = [\sigma(\mathrm{Y})^2 + 0{,}279\,\sigma(\mathrm{R\text{-}Y})^2 + 0{,}088\,\sigma(\mathrm{B\text{-}Y})^2]^{1/2} \tag{2}$$

NOTE The coefficients of the chrominance variances, σ (R-Y) and σ (B-Y), in Formula (2) were updated in this International Standard due to new coefficients being introduced in ISO 12232:2006. The revision of the coefficients was necessary due to a revised experimental procedure that indicated that the original values for the coefficients overemphasized the contribution of chrominance noise to perception.[4]

4.8 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 dynamic range. The minimum requirement is to specify the midtone signal-to-total-noise ratio and the dynamic range of the digital camera under test. In addition, 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.

NOTE The noise measurement procedures described in this International Standard are intended to measure the temporal and fixed pattern noise standard deviations spatially over the image. They do not take into account the variation in the mean pixel value between individual frames captured by a DSC. This type of frame to frame variation in mean pixel value may be introduced due to changes in ambient temperature, camera power supply or lighting flicker. The illumination and temperature requirements specified in the standard will minimize these variations. 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.

5.1.1 Uniform field noise measurement methods

The method of measuring the uniform field noise will be dependent on the type of camera and its level of exposure automation. If the camera lens can be removed, then the sensor noise level can be measured without any shading effects from the lens. The noise measurement procedures for DSCs having removable lenses or manual exposure control are described in 5.2 and 5.3 respectively.

On automatic exposure cameras having through the lens (TTL) exposure control and no manual exposure control override capability, the test chart and measurement methods described in 5.4 shall be used.

5.1.2 Test densities

For the noise measurement procedures described in 5.2 and 5.3 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 (1 % transmittance) shall be used to provide a “black reference” signal level to determine the camera dynamic range.

5.1.3 Adjustment of illumination, test density placement and camera lens focus

The light source and diffuser (where applicable) 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”.

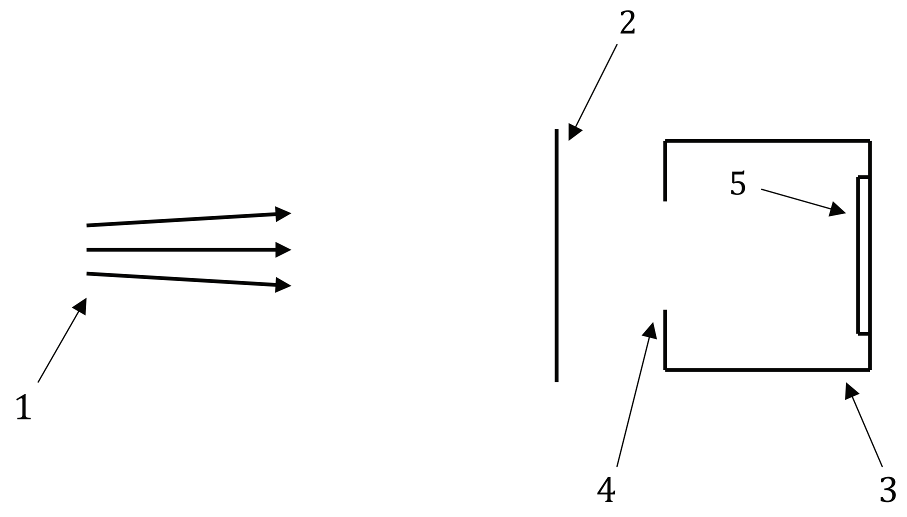
Test densities (when used) shall completely cover the area exposed, when the camera lens is removed.

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

5.2 Measurement of a DSC having a removable lens

5.2.1 General

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 1. Reflective surfaces shall not be placed where they could cause additional illumination to be incident on the sensor.



Key

1 light source

2 test density

3 camera under test

4 lens removed

5 digital image sensor

Figure 1 — Illumination for cameras with removable lenses

5.2.2 The focal plane OECF shall be measured according to ISO 14524.

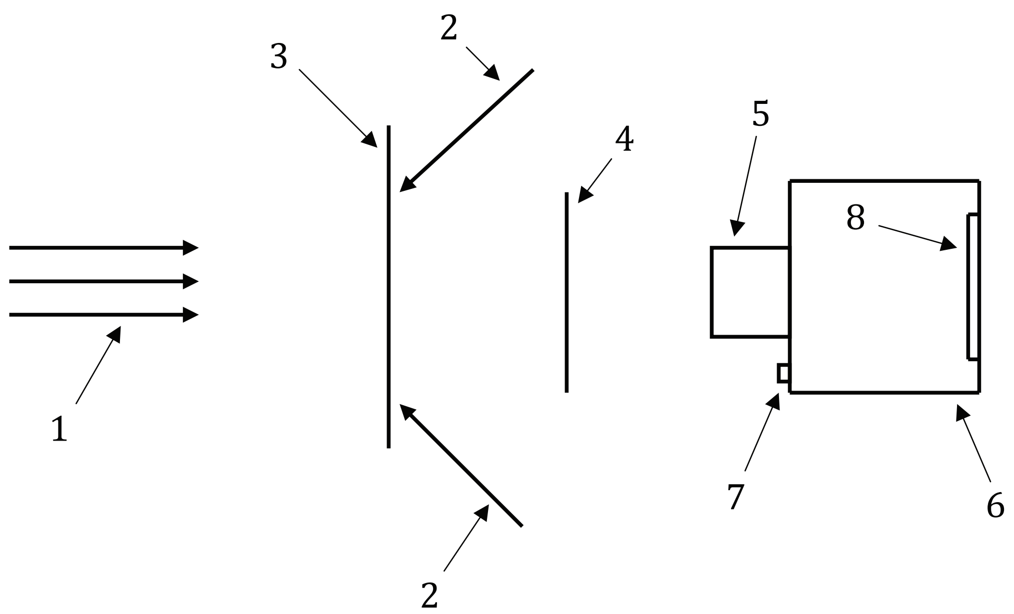
5.3 Measurement of a DSC having manual exposure control

5.3.1 General

These measurements shall be used for all cameras that use manual exposure control, or exposure control based on a separate exposure control sensor.

5.3.2 The camera OECF shall be measured according to ISO 14524.

5.3.3 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).



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 using a test chart

5.4.1 General

These measurements shall be used for TTL automatic exposure cameras having no manual exposure control override.

5.4.2 The camera OECF shall first be measured in accordance with ISO 14524.

5.4.3 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 14524:2009. 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 a ND reflectance patch may 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.

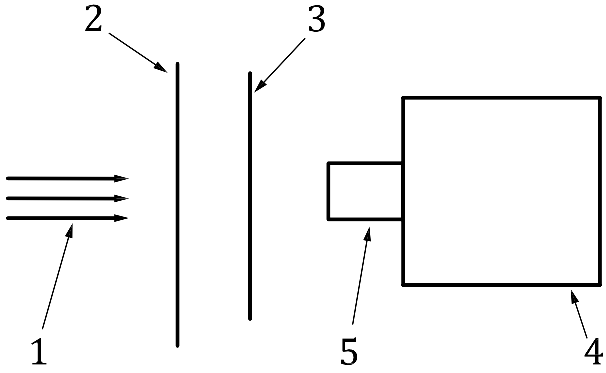
For a camera that generates signals in other colour encodings the light source should be adjusted to give an output pixel value equal to the encoding values that correspond to a perceptual midtone for the background of the OECF test chart. The perceptual midtone value achieved should be reported.

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.

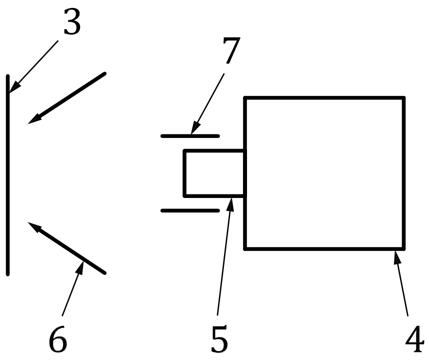
5.4.4 The test chart shall be a Camera OECF test chart conformant with ISO 14524. The test chart can be either transmissive or reflective (see Figure 3). The chart shall have sufficient density range so that the lightest patch is at or above the camera highlight clipping level when the test chart background 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.

5.4.5 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.

5.4.6 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 5.4.5.



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 3 — Test chart noise measurements

6 Calculation and reporting of results

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 measurements made according to 5.2 and 5.3, a minimum of eight images shall be captured for each exposure or test density, respectively. The mean pixel value and the rms noise level shall be determined from an area of not less than 64 × 64 pixels in the centre of each of the images.

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

6.2 Signal-to-noise ratios — large area

6.2.1 General

For the method described in 5.2 the signal-to-noise ratio is determined from data captured at an exposure that is 13 % of the reference exposure. For the methods described in 5.3 and 5.4 the signal-to-noise ratio is determined from data captured at a luminance that is 13 % of the reference luminance. In methods 5.2 and 5.3 the exposure and luminance are varied respectively by using the densities specified in 5.1.2. In method 5.4 the signal-to-noise ratio is determined by using the density patches on the test chart specified in ISO 14524.

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

The method for determining the reference luminance and the luminance value at which the signal-to-noise ratio is calculated is described in section 6.2.2. In section 6.2.6 the method for determining the reference exposure and the exposure value at which the signal-to-noise ratio is calculated is summarized.

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

For the case where the camera OECF has been measured using methods 5.3 and 5.4, the reference luminance shall be determined as the log luminance value corresponding to a pixel value of 245 on the camera OECF curve. If necessary, an interpolation function may be used to determine the reference luminance value. The above applies to camera systems that generate 8-bit sRGB signals as defined in IEC 61966-2-1. 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 level. For example, 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.

Mathematically, the log luminance value that is the camera reference luminance is defined for 8-bit sRGB signals as:

$$R_{\text{ref}} = S^{-1}(I)\big|_{I=245} \tag{3}$$

where

R_{ref} is the log luminance value at the reference luminance;

S^{-1} is the inverse of the camera OECF curve, S;

I is the pixel value.

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

EXAMPLE A camera system that creates 8-bit sRGB images results 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 measured at the luminance value that is 13 % of the luminance at the reference luminance. This can be expressed as:

$$L_{\text{SNR}} = 0{,}13 \times L_{\text{ref}} \tag{4}$$

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, R_{ref}.

Taking logarithms of both sides in Formula (4):

$$R_{\text{SNR}} = R_{\text{ref}} + \log(0{,}13) \tag{5}$$

Where $R_{\text{SNR}} = \log(L_{\text{SNR}})$ and $R_{\text{ref}} = \log(L_{\text{ref}})$. 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(0,13)| below the reference luminance, R_{ref}.

6.2.3 Determining the signal-to-total noise ratio

The signal-to-total noise ratio, Q_{total}, is determined by:

$$Q_{\text{total}} = \frac{g_{\text{SNR}} L_{\text{SNR}}}{\sigma_{\text{total}}} \tag{6}$$

The incremental gain, g_{SNR}, is the first derivative of the OECF curve and, for the case of the camera OECF, is determined at the log luminance value of R_{SNR}. by the method given in ISO 14524. The noise is calculated from the standard deviations with the precision defined by the digital resolution used for the maximum digital encoding value. Where necessary, an interpolation function may be used to determine an accurate estimate of signal-to-total noise ratio.

The average of the total noise, σ_{total}, is the average of the standard deviations of n samples of the total noise and is given by:

$$\sigma_{\text{total}} = \sqrt{\frac{1}{n} \sum_{j=1}^{n} \sigma_{\text{total},j}^2} \tag{7}$$

6.2.4 Determining the fixed pattern signal-to-noise ratio

The fixed pattern signal-to-noise ratio is determined by averaging a minimum of eight exposures and then applying a correction to determine the true level of the fixed pattern noise. The fixed pattern noise is converted to an input referred incremental signal-to-noise ratio for the test 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:

$$Q_{\text{fp}} = \frac{g_{\text{SNR}} L_{\text{SNR}}}{\sigma_{\text{fp}}}$$

The average of the fixed pattern noise is:

$$\sigma_{\text{fp}} = \sqrt{\sigma_{\text{ave}}^2 - \frac{1}{n-1} \sigma_{\text{diff}}^2} \tag{8}$$

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_{diff} is the average standard deviation of the pixel values of all the differences of the average and the individual images that make up the average.

The average of the sum of all the difference images is:

$$\sigma_{\text{diff}}^2 = \frac{1}{n} \sum_{j=1}^{n} \sigma_{\text{diff},j}^2 \tag{9}$$

where $\sigma_{\text{diff},j}$ is the standard deviation of the pixel values of the difference of the average and the jth image.

The derivation of Formulae (8) and (9) is shown in Annex A.

6.2.5 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 determine the true level of the temporal noise. The temporal noise is converted to an input referred incremental signal-to-noise ratio for the test density, and reported as the DSC temporal signal-to-noise ratio.

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

$$Q_{temp} = \frac{g_{SNR} L_{SNR}}{\sigma_{temp}}$$

The average of the temporal noise is:

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

where

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

σ_{diff} is the average standard deviation of the pixel values of all the differences of the average and the individual images that make up the average, shown in more detail in 6.2.4.

6.2.6 Determining the reference exposure and exposure value for calculating signal-to-noise ratio

For the case where the focal plane OECF has been measured using the method described in 5.2, 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 6.2.2 to 6.2.5 shall be applied.

6.3 DSC dynamic range

The DSC dynamic range is reported as the ratio of the maximum unclipped input luminance level, L_{sat}, and the minimum input luminance level, L_{min}, with a signal-to-temporal noise-ratio of at least 1. The dynamic range, D_R, is given by:

$$\mathrm{D}_R = \frac{L_{sat}}{L_{min}} \tag{11}$$

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

$$L_{min} = \frac{\sigma_{temp,2}}{g_2} \tag{12}$$

where $\sigma_{temp,2}$ is the black temporal noise measured with the test density of 2,0 and g_2 is the incremental gain measured with the test density of 2,0.

NOTE As the incremental gain approaches zero it becomes impossible to determine the incremental signal-to-temporal noise ratio.

The black temporal noise is derived in a similar way to the temporal noise in 6.2.5, by measuring the standard deviation of the difference of each image and the average image, and then applying a correction to determine the true level of the temporal noise:

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

where

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

σ_{diff} is the average standard deviation of the pixel values of all the differences of the average and the individual images that make up the average, shown in more detail in 6.2.4.

NOTE If possible the minimum luminance level should be determined from a density that provides an incremental signal-to-temporal-noise ratio of 1. It is recommended that a transmissive chart with a high dynamic range is used to determine DSC dynamic range. If the dynamic range of the test chart used is not sufficiently high then a transmittance equal to 0.01 of the clipping transmittance should be used to determine the DSC dynamic range.

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

$$D_{\text{R,density}} = \log_{10}(L_{\text{sat}}) - \log_{10}(L_{\text{min}}) \qquad \text{densities} \tag{14}$$

If reported in terms of f-stops, then DSC dynamic range is given as:

$$D_{\text{R,fstop}} = \frac{\log_{10}(L_{\text{sat}}) - \log_{10}(L_{\text{min}})}{\log_{10}(2{,}0)} \qquad \text{f-stops} \tag{15}$$

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 calculated 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:

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

A.1.2 Analysis

The following notation shall be used for the noise component analysis.

$p(x,y)$	are the values of pixel (x,y) of an image;
$p_{fp}(x,y)$	is the fixed pattern part of the image;
$p_{temp}(x,y)$	is the temporally varying part of the image;
σ_{total}	is the standard deviation of $p(x,y)$, total noise;
σ_{fp}	is the standard deviation of $p_{fp}(x,y)$, fixed pattern noise;
σ_{temp}	is the standard deviation of $p_{temp}(x,y)$, temporal noise;
σ_{ave}	is the standard deviation of the pixel values of the average of several images;
σ_{diff}	is the standard deviation of the pixel values of the difference between two images.

A.1.3 Fixed pattern noise

The fixed pattern noise is determined by analysing the average image of n images, p_1 to p_n. Since the fixed pattern part of the image is, by definition, equal for all images, the pixel values of the average image are:

$$\bar{p}(x,y)=\frac{1}{n}\sum_{j=1}^{n}p_j(x,y)=p_{\mathrm{fp}}(x,y)+\frac{1}{n}\sum_{j=1}^{n}p_{\mathrm{temp},j}(x,y)$$

Since there is no correlation of the temporal noise of different images, the variance of the pixel values of the average image is:

$$\sigma_{\mathrm{ave}}^2=\sigma_{\mathrm{fp}}^2+\frac{1}{n^2}\sum_{j=1}^{n}\sigma_{\mathrm{temp},j}^2$$

If the mean of the variances of the temporal noise is denoted as σ_{temp}^2, then

$$\sigma_{\mathrm{ave}}^2=\sigma_{\mathrm{fp}}^2+\frac{1}{n}\sigma_{\mathrm{temp}}^2 \tag{A.2}$$

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:

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

The mean of the variances of the pixel values of the difference images is then:

$$\sigma_{\mathrm{diff}}^2=\frac{1}{n}\sum_{j=1}^{n}\sigma_{\mathrm{diff},j}^2=\frac{n-1}{n^2}\sum_{j=1}^{n}\sigma_{\mathrm{temp},j}^2=\frac{n-1}{n}\sigma_{\mathrm{temp}}^2$$

The standard deviation of the temporal noise is thus given by:

$$\sigma_{\mathrm{temp}}=\sqrt{\frac{n}{n-1}\sigma_{\mathrm{diff}}^2}$$

Using this result, the standard deviation of the fixed pattern noise can be obtained with the result derived in Formula B.2:

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

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) To exploit the full information of the images captured, first the average image is calculated and the standard deviation of the average image is evaluated to give σ_{ave}.

b) The second step is to calculate the difference of each image and the average image.

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

d) The fourth step is to calculate the mean of all squared standard deviations of the difference images, to give:

$$\sigma_{\text{diff}}^2 = \frac{1}{8}\sum_{j=1}^{8}\sigma_{\text{diff},j}^2$$

e) The standard deviation of the temporal noise is then calculated as:

$$\sigma_{\text{temp}} = \sqrt{\frac{8}{7}\sigma_{\text{diff}}^2} \qquad \text{(A.3)}$$

f) The standard deviation of the fixed pattern noise is calculated as

$$\sigma_{\text{fp}} = \sqrt{\sigma_{\text{ave}}^2 - \frac{1}{7}\sigma_{\text{diff}}^2} \qquad \text{(A.4)}$$

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 σ_{total} 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

Image *n*	**Mean pixel value**	σ_{total}	σ_{diff}
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.

Steps 2 to 4: The mean of the squared standard deviations of the eight difference images is 3,63 (from Table A.1), i.e. $\sigma_{\text{diff}}^2 = 3{,}63$.

Step 5: Formula (A.3) 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.4), 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 average 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. The visual noise is evaluated as an output referred noise, unlike the standard camera signal-to-noise ratio described in 6.2. The general steps of the method are given below.

a) An image of the OECF target is taken as described in 5.4.

b) The RGB image shall be 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*u*v* colour space, defined by the CIE.

g) The weighted sums of the three standard deviations of the filtered noise 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.

Visual noise measurement is an area where there is considerable ongoing research activity. Aspects of the method for measuring visual noise may change in future revisions of this International Standard.

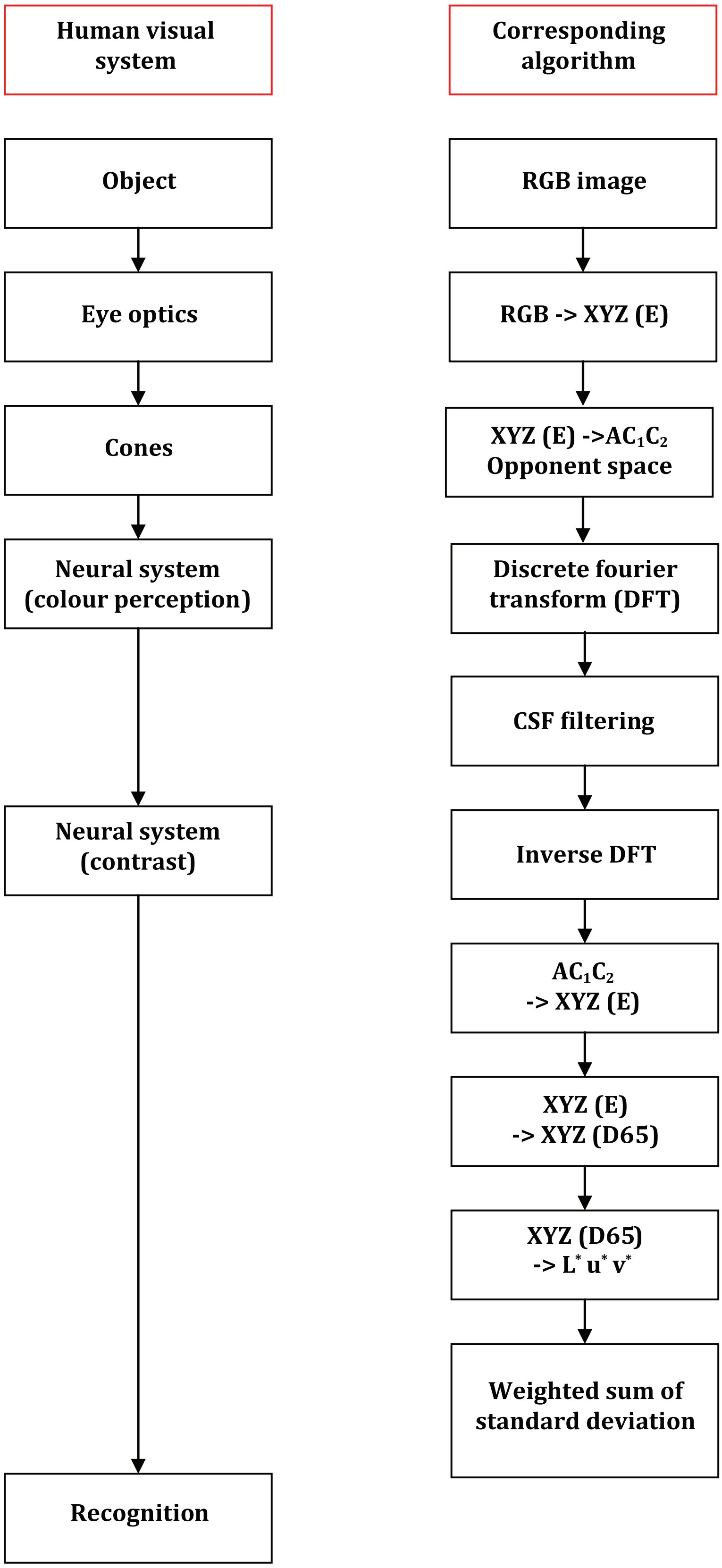


Figure B.1 — Human visual system and corresponding visual noise algorithm

B.2 Algorithm used for the visual noise measurements

B.2.1 RGB to XYZ(E)

The R, G and B signals should be as defined in the sRGB standard IEC 61966-2-1. The R, G and B pixel values of the image are linearized and the viewer-observed black point unscaled using the sRGB characterization equation:

$$C_\mathrm{l} = 0{,}0125 + 0{,}0764319 \times C_\mathrm{n} \quad \text{for} \quad C_\mathrm{n} \le 0{,}04045$$

$$C_\mathrm{l} = 0{,}0125 + 0{,}868423 \times (0{,}055 + C_\mathrm{n})^{2,4} \quad \text{for} \quad C_\mathrm{n} > 0{,}04045 \qquad \text{(B.1)}$$

$$C_\mathrm{n} = C_\mathrm{c} / C_\mathrm{m}$$

Where C_c represents the R, G and B sRGB image pixel values, C_m represents the maximum sRGB pixel value, e.g. 255 for 8-bit per component sRGB, C_n represents the normalized nonlinear R, G and B sRGB values and C_l represents the linearized R, G and B sRGB values.

The linearized sRGB values are then converted to XYZ (E) using a conversion matrix that is determined as follows. A chromatic adaptation transform (CAT) matrix to convert XYZ values from D65 to Illuminant E using the linearized Bradford transformation is derived. The CAT matrix is given in Formula B.2:

$$\begin{bmatrix} X_\mathrm{E} \\ Y_\mathrm{E} \\ Z_\mathrm{E} \end{bmatrix} = \begin{bmatrix} 1{,}05030 & 0{,}02710 & -0{,}02329 \\ 0{,}03909 & 0{,}97294 & -0{,}00927 \\ -0{,}00241 & 0{,}00266 & 0{,}91789 \end{bmatrix} \cdot \begin{bmatrix} X_\mathrm{D65} \\ Y_\mathrm{D65} \\ Z_\mathrm{D65} \end{bmatrix} \qquad \text{(B.2)}$$

The linearized Bradford matrix used to derive the CAT matrix is given in Formula B.3:

$$M_\mathrm{BFD} = \begin{bmatrix} 0{,}8951 & 0{,}2664 & -0{,}1614 \\ -0{,}7502 & 1{,}7135 & 0{,}0367 \\ 0{,}0389 & -0{,}0685 & 1{,}0296 \end{bmatrix} \qquad \text{(B.3)}$$

The matrix needed to transform linearized sRGB values to XYZ (E) values is found by multiplying the sRGB to XYZ (D65) matrix from IEC 61922-2-1 with the matrix in Formula B.2. This results in the transform matrix, B.4:

$$\begin{bmatrix} X_\mathrm{E} \\ Y_\mathrm{E} \\ Z_\mathrm{E} \end{bmatrix} = \begin{bmatrix} 0{,}43846 & 0{,}39219 & 0{,}16940 \\ 0{,}22279 & 0{,}70872 & 0{,}06849 \\ 0{,}01729 & 0{,}11045 & 0{,}87221 \end{bmatrix} \cdot \begin{bmatrix} \mathrm{R} \\ \mathrm{G} \\ \mathrm{B} \end{bmatrix} \qquad \text{(B.4)}$$

NOTE If the image data are not in the sRGB colour encoding space and an ICC profile is present, then the image data should be 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:

$$\begin{bmatrix} A \\ C_1 \\ C_2 \end{bmatrix} = \begin{bmatrix} 0 & 1{,}0 & 0 \\ 1{,}0 & -1{,}0 & 0 \\ 0 & 0{,}4 & -0{,}4 \end{bmatrix} \cdot \begin{bmatrix} X_\mathrm{E} \\ Y_\mathrm{E} \\ Z_\mathrm{E} \end{bmatrix} \qquad \text{(B.5)}$$

The opponent colour space, A, C_1 and C_2, is described in reference [5]

B.2.3 Discrete Fourier Transform

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 $\hat{C}_2$:

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

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 Johnson and Fairchild [12] was selected for this International Standard. 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:

$$W_{\text{lum}}(f) = \frac{(K + a \cdot f^{c}) \cdot e^{-\text{bf}}}{K} \qquad \text{(B.7)}$$

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	0,9
K	46

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

NOTE 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.

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

$$W_{\text{chrom}}(f) = \frac{a_1 \cdot e^{-\text{b}_1 \text{f}^{\text{c}1}} + a_2 \cdot e^{-\text{b}_2 \text{f}^{\text{c}2}} - S}{K} \qquad \text{(B.8)}$$

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
a1	109,1413	7,0328
b1	0,0004	0
c1	3,4244	4,2582
a2	93,5971	40,691
b2	0,0037	0,1039
c2	2,1677	1,6487
K	202,7384	40,691
S	0	7,0328

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

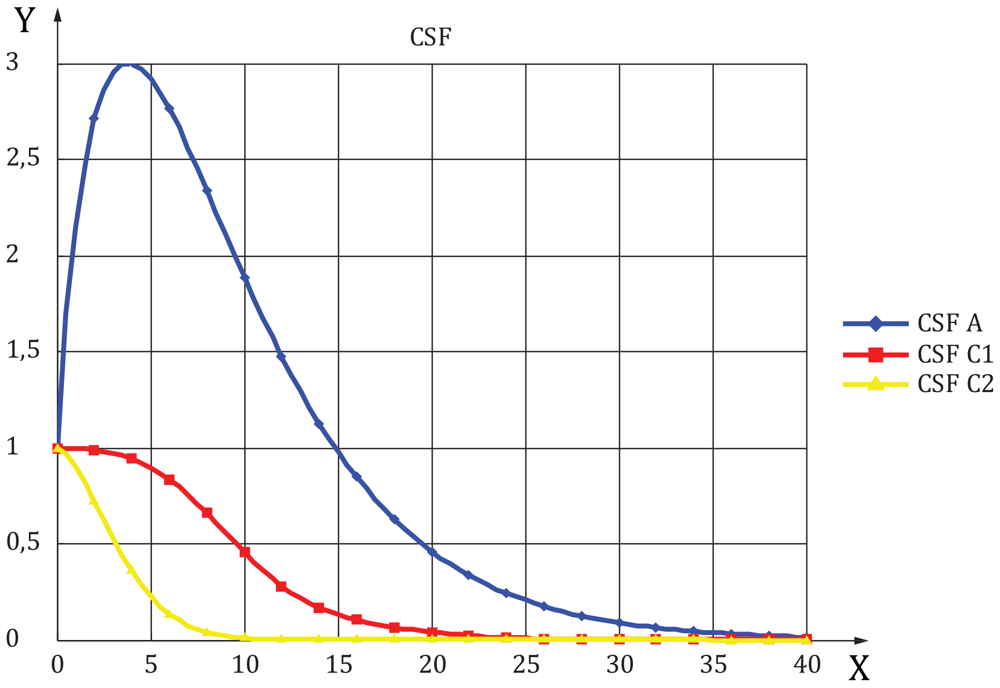


Figure B.2 — Contrast sensitivity of the function of human eye used in ISO 15739

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 cycle at the Nyquist frequency is given by:

$$\tan(\alpha) = \frac{2P}{D} \Rightarrow \alpha = \frac{180°}{\pi} \arctan\left(\frac{P}{D}\right)$$

where

P is the pixel pitch;

D is the viewing distance.

The frequency in cycles per degree is given as:

$$f\left[\frac{\text{cycles}}{\text{degree}}\right] = f\left[\frac{\text{cycles}}{\text{pixel}}\right] \cdot \frac{1}{\alpha}$$

The image is then filtered using:

$$\begin{aligned} \hat{A}_f &= \hat{A} W_A \\ \hat{C}_{1,f} &= \hat{C}_1 W_{C,1} \\ \hat{C}_{2,f} &= \hat{C}_2 W_{C,2} \end{aligned} \qquad \text{(B.9)}$$

W_A is the equation for the CSF given in Formula (B.7) with the coefficients in Table B.1. $W_{C,1}$ and $W_{C,2}$ are derived by substituting the coefficients for C_1 and C_2 ,respectively, in Table B.2 into the equation for the CSF given in B.8.

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:

$$\begin{aligned} \hat{A}_f &\xrightarrow{\text{inverseDFT}} A_f \\ \hat{C}_{1,f} &\xrightarrow{\text{inverseDFT}} C_{1,f} \\ \hat{C}_{2,f} &\xrightarrow{\text{inverseDFT}} C_{2,f} \end{aligned} \qquad \text{(B.10)}$$

If the output of the inverse discrete Fourier transform contains complex values, then the magnitude of the output should be taken.

B.2.6 Opponent Space AC_1C_2 into XYZ(E)

The three opponent colour responses, A_f, $C_{1,f}$ and $C_{2,f}$, 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:

$$\begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix} = \begin{bmatrix} 1{,}0 & 1{,}0 & 0 \\ 1{,}0 & 0 & 0 \\ 1{,}0 & 0 & -2{,}5 \end{bmatrix} \cdot \begin{bmatrix} A_f \\ C_{1,f} \\ C_{2,f} \end{bmatrix} \qquad \text{(B.11)}$$

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 B.2. The matrix is given as:

$$\begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} = \begin{bmatrix} 0{,}95315 & -0{,}02661 & 0{,}02392 \\ -0{,}03827 & 1{,}02885 & 0{,}00942 \\ 0{,}00261 & -0{,}00305 & 1{,}08949 \end{bmatrix} \cdot \begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix} \quad \text{(B.12)}$$

If any tristimulus values are negative then the pixel should be omitted in the calculation of Formula (B.16). If the resultant *N* is less than two-thirds of the original *N*, the data of the patch level should be omitted.

B.2.8 XYZ (D65) to L*u*v*

The tristimulus values are converted into the CIE L*u*v* colour space as follows:

$$\begin{aligned} L^* &= \left(\frac{116}{12}\right)^3 \times \frac{Y}{Y_n} && \text{for } \frac{Y}{Y_n} \le \left(\frac{24}{116}\right)^3 \\ L^* &= 116 \times \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16 && \text{for } \frac{Y}{Y_n} > \left(\frac{24}{116}\right)^3 \end{aligned} \quad \text{(B.13)}$$

$$\begin{aligned} u^* &= 13 \times (u' - u'_n) \times L^* \\ v^* &= 13 \times (v' - v'_n) \times L^* \end{aligned} \quad \text{(B.14)}$$

and, for the D65 white-point,

$$\begin{aligned} u'_{nD65} &= \frac{4X_{WP}}{X_{WP} + 15Y_{WP} + 3Z_{WP}} = \frac{4 \times 95{,}05}{95{,}05 + 15 \times 100 + 3 \times 108{,}91} = 0{,}1978 \\ v'_{nD65} &= \frac{9Y_{WP}}{X_{WP} + 15Y_{WP} + 3Z_{WP}} = \frac{9 \times 100}{95{,}05 + 15 \times 100 + 3 \times 108{,}91} = 0{,}4683 \end{aligned} \quad \text{(B.15)}$$

NOTE The CIE L*u*v* colour space is used because it provides very good perceptual uniformity for small colour differences.[13]

B.2.9 Determining the standard deviation for each grey patch

The standard deviation of the colour noise along the three axes (L*, u*, v*) of the uniform colour space is given as:

$$\begin{aligned} \sigma_{L^*} &= \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(x_{L^*_i} - \overline{x_{L^*}}\right)^2} \\ \sigma_{u^*} &= \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(x_{u^*_i} - \overline{x_{u^*}}\right)^2} \\ \sigma_{v^*} &= \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(x_{v^*_i} - \overline{x_{v^*}}\right)^2} \end{aligned} \quad \text{(B.16)}$$

where *N* is equal to the number of evaluated pixels in the patch. The number of pixels, *N*, shall be equal or greater than 64.

B.2.10 The weighted sum representing the visual noise

The visual noise is defined as the sum of the three standard deviations of the colour noise along the L*, u* and v* axes.[5] [6] The equation to determine the visual noise value is as follows:

$$V = \sigma_{L*} + 0{,}852 \cdot \sigma_{u*} + 0{,}323 \cdot \sigma_{v*} \tag{B.17}$$

Formula (B.17) is defined only to measure the visual noise for the purpose of spatial frequency weighting.

B.3 Visual noise measurements

B.3.1 Test conditions

B.3.1.1 The test chart is the chart described in ISO 14524.

B.3.1.2 The method for illuminating and exposing the test chart is described in 5.4.

B.3.1.3 A high contrast back illuminated transmissive 20 patch OECF test chart with a contrast ratio of 10,000:1 is recommended.

B.3.2 Test method and evaluation of visual noise measurements with software

B.3.2.1 The calculation of visual noise can be performed with the Windows executable (or equivalent) software. The evaluation procedure is as follows.

B.3.2.2 An image of the test chart is selected.

B.3.2.3 The ICC profile associated with the image is selected.

B.3.2.4 The maximum frequency in cycles per degree that results from the image pixel size and viewing distance is entered.

B.3.2.5 A window displaying the test chart image will open and a small rectangle indicating the Region Of Interest (ROI) will appear. The evaluation procedure using the software shall be as follows:

a) Select the ROI rectangle and position it over a patch;

b) Resize the rectangle so that it is fully contained within the patch boundary;

c) The computed value for the visual noise for the patch is shown at the bottom of the window together with the values for the standard deviation of luminance, u* and v*.

NOTE The software and Matlab source code can be downloaded from the Society for Imaging Science and Technology (IS&T)1). The Matlab Compiler Runtime 7.9 is required to be installed before the executable can be run.

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 Formula (B.1), (B.4) and (B.13), 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.

1) http://www.imaging.org

Table B.3 — Example visual noise data

Average sRGB pixel value	Lightness	Visual noise level
C	**L***	*H*
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
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 = 1000mm Size of output pixel = 0,266 mm		

Annex C
(informative)

Removing low frequency variations from the image data

C.1 General

The lenses in many DSCs exhibit 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 should be removed from the digital image data before measuring the noise, since they degrade (increase) the measured R, G and B noise standard deviations. If the non-uniformities are of concern and it is required to use a high pass filter to remove the low frequency variations in the image then the 13 × 13 tap FIR high pass filter in this annex may be used. The filter is convolved with the linearized R, G, and B image data to remove the low frequency variations from the image data. The spatial frequency response of this FIR filter greatly attenuates the lowest image spatial frequencies, including the lens non-uniformity.

The filter should only be applied if the test chart occupies no more than 4 megapixels of the captured image area. The high pass filter should 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 following procedure should be applied to remove the low frequency variations using the high pass filter:

a) The test chart should be captured within an area corresponding to four megapixels. For example, for a test chart with 4:3 aspect ratio, the chart should occupy no more than 2312 × 1736 pixels on the image sensor. If necessary, the camera to chart distance may be varied and the test chart may be placed on a uniform reflectance background with a density that is equal to the chart background density.

b) The R, G and B pixel values of the captured image should be linearized using the appropriate characterization function for the colour encoding space used.

c) The DC value of each patch in the linearized camera OECF test chart should be estimated. This may be accomplished by calculating either the average or the median R, G and B pixel value for each patch in the linearized OECF test chart image.

d) The 13 × 13 tap high pass FIR filter should be applied to the linearized image. Table C.1 displays the bottom-right quadrant of the 13 × 13 kernel that should be used. The whole 13 × 13 kernel is defined by reflecting the bottom 6 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.

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. Care must be taken to ensure that negative filter output values are not clipped to zero prior to adding the mean patch value.

e) The DC value calculated in c) should be added to the corresponding high pass filtered patch in d).

f) The R, G and B data should be gamma corrected by applying the relevant nonlinear function for the colour encoding space.

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

This 13 × 13 FIR filter removes the DC component of the image, and thus the mean signal value D cannot be computed from the filter output values. Care must be taken to ensure that negative filter output values are not clipped to zero prior to adding the mean patch value.

Annex D
(informative)

Recommended procedure for determining signal to noise ratio

D.1 Procedure

Annex D gives the recommended procedure for determining signal-to-total noise ratio described in the main body of this International Standard. A similar procedure may be applied to determine fixed pattern and temporal noise signal-to-noise.

a) Determine the system OECF according to ISO 14524. For cameras with removable lenses, the focal plane OECF may be measured. The camera OECF is measured for cameras with fixed lenses and with non-overrideable automatic exposure control.

b) Compute a luminance component from red, green and blue levels according to Formula (1).

c) Determine the standard deviation of pixels values in each 64 × 64 area selected for the OECF measurement using Formula (2) to calculate the standard deviation of the camera noise, $\sigma(D)$.

d) Determine the incremental gain of the system at each target patch luminance, $g(L_\mathrm{j})$, by averaging the change in pixel value by the change in luminance when going from the luminance immediately below the luminance to it with the change in pixel value divided by the change in luminance when going from the luminance to the luminance immediately above it. This is shown in Formula D.1 below. Incremental gain values should not be determined for the end point luminances using this method.

$$g(L_j)=\frac{1}{2}\left[\frac{I(L_j)-I(L_i)}{L_j-L_i}+\frac{I(L_k)-I(L_j)}{L_k-L_j}\right] \quad \text{(D.1)}$$

where I is the pixel value, and L_i, L_j and L_k are the three luminance levels immediately following each other in an OECF chart.

A similar procedure is used to determine exposure incremental gain, with “exposure” substituted for “luminance” in the above procedure.

e) Calculate the signal to total noise values as a function of luminance or exposure using Formula (D.2) and Formula (7). The luminance of the patch for which the signal-to-total noise is being calculated is given by L_j.

$$Q_\mathrm{total}=\frac{g\left(L_j\right)L_j}{\sigma_\mathrm{total}} \quad \text{(D.2)}$$

f) Determine a luminance value corresponding to the reference luminance as described in 6.2.2.

g) Determine the luminance value, L_SNR at which the signal to total noise ratio is measured. This may be determined as the inverse logarithm of the log luminance value that is |log(0,13)| below the log luminance value of the reference exposure. See 6.2.2.

h) Calculate the signal-to-total noise value at the luminance value determined in g) from the curve of signal to total noise values computed in e). If the value of L_SNR is not exactly equal to the luminance of a given patch, then it is recommended that an interpolation function be used to obtain an accurate estimate of signal-to-total noise. For example, a linear interpolation function may be used to compute the signal-to-total noise value from two points on the signal-to-total noise curve; one point with the luminance value immediately below the luminance, L_SNR, and the other with the luminance immediately above, L_SNR.

Annex E
(informative)

Recommended practical viewing conditions for various output media

The presence of artefacts in an image can degrade its quality. The amount by which quality is degraded depends on the visibility of the artefacts. To determine the visibility of an imaging artefact it is important to know the size of the image, the viewing distance and the lighting conditions in which the image is viewed by an observer. One example of an imaging artefact is image noise. As the image size decreases, the pixel size decreases and the observer is unable to distinguish individual pixels, or even groups of pixels. The variation of luminance or colour from pixel to pixel is no longer visible to the observer. This has the effect of reducing the visibility of image noise. If the same image is viewed at a magnification of 100 % on a computer monitor (1 pixel = 1 monitor element), then the image can appear to have a much higher noise level due to the fact that the observer is able to distinguish individual pixels.

The following viewing conditions are recommended for common image viewing situations:

a) **Consumer Photo Print Viewing:** A 100 × 150 mm print is viewed from a distance of 250 mm. This is widely accepted as the shortest distance for relaxed viewing by a human observer. The lighting conditions should be compliant with ISO 3664, ISO viewing condition P2 (CIE Illuminant D50 at 500 lx ± 125 lx). The estimated average resolution limit of the human eye is 1/60°. This corresponds to a spatial resolution of 0,073 mm (about 350 pixels per inch) for a viewing distance of 250 mm. This means that the printing process has to exceed this resolution or it may be the limiting factor for the spatial quality estimation.

b) **Computer Display Viewing:** The image is viewed at 100 % magnification on a computer display from a distance of 600 mm, and the display resolution is approximately 4 pixels per mm. The luminance of the display should be greater than 100 cd/m^2 and the chromaticity of the white displayed on the colour monitor should approximate that of D65. The ambient illumination and other aspects of the viewing conditions should be compliant with the conditions for appraisal of images displayed on colour monitors specified in ISO 3664.

c) **Professional Photo Print Viewing:** A 400 × 600 mm print viewed from 750 mm is a typical example for a framed print mounted on a wall. The lighting conditions should be compliant with ISO 3664, ISO viewing condition P2 (CIE Illuminant D50 at 500 lx ± 125 lx).

d) **Cell Phone Viewing:** The image is viewed on a 89 mm (diagonal) display with 960 by 640 pixels from a distance of 250 mm. The luminance of the display, ambient illumination and other aspects of the viewing conditions should be compliant with the conditions for appraisal of images displayed on colour monitors specified in ISO 3664.

e) **HDTV Viewing:** The image is viewed full screen on a 1 920 × 1 080 pixel, 1 070 mm (diagonal) HDTV monitor with horizontal viewing angle under 30° representing a viewing distance of 1,74 m. If the aspect ratio of the image is different to the display aspect ratio the image shall be displayed so its height fills the height of the display and the areas to the left and right of the image show the black level of the monitor. All aspects of the viewing conditions should be compliant with the conditions for appraisal of images displayed on colour monitors specified in ISO 3664.

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