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INTERNATIONAL STANDARD

colour inside

**Eyewear display –
Part 21-20: Specific measurement methods for VR image quality – Screen door effect**

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The text of this International Standard is based on the following documents:

Draft	Report on voting
110/1433/FDIS	110/1444/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 63145 series, published under the general title *Eyewear display*, can be found on the IEC website.

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EYEWEAR DISPLAY –

Part 21-20: Specific measurement methods for VR image quality – Screen door effect

1 Scope

This part of IEC 63145 specifies the standard measurement conditions and measurement methods for determining the screen door effect (SDE), which is one of the image quality aspects of eyewear displays of virtual reality (VR) type.

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.

IEC 63145-1-2, *Eyewear display – Part 1-2: Generic – Terminology*

IEC 63145-20-10:2019, *Eyewear display – Part 20-10: Fundamental measurement methods – Optical properties*

IEC 63145-20-20, *Eyewear display – Part 20-20: Fundamental measurement methods – Image quality*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 63145-1-2 and the following apply.

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

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
screen door effect
SDE
visibility of inter-pixel areas due to a spatial display resolution lower than that of the human visual system or to an insufficient pixel fill-factor/aperture ratio

3.2 Abbreviated terms

2D	two dimensional
CCD	charge-coupled device
DUT	device under test
LMD	light measuring device
MWA	moving window average
VR	virtual reality

4 Standard measurement conditions

Standard measurement conditions (standard environmental conditions, power supply, warm-up time, dark room conditions) shall comply with IEC 63145-20-10 and IEC 63145-20-20.

5 Measurement systems

5.1 Standard coordinate system

The standard coordinate system shall comply with IEC 63145-20-10 and IEC 63145-20-20.

5.2 Measurement equipment

5.2.1 2D imaging LMD

The 2D imaging light measuring device (LMD) shall comply with IEC 63145-20-10 and IEC 63145-20-20, if not described otherwise in the following paragraphs.

The 2D imaging LMD (using a two-dimensional sensor such as a CCD) is a kind of a filter-type LMD. The performances of the 2D imaging LMD shall comply with the LMD specified in IEC 63145-20-10 and IEC 63145-20-20. A 2D imaging LMD that can capture at least a ±2,5° measurement field shall be used. The measurement field shall be less than 18°. The valid measurement field angle of the 2D imaging LMD shall be confirmed and the peripheral image of the 2D imaging LMD shall confirm the absence of vignetting. The 2D imaging LMD should have a minimum performance of 30 cycles per degree with 50 % Michelson contrast at the entrance pupil of 2 mm to 5 mm. The optical measurement capabilities of the LMD, such as luminance and spectral radiance, should be traceable to national metrology standards under the same conditions (for example entrance pupil size, measurement field angle and focus distance in some structures).

NOTE 1 The measurement field of some 2D imaging LMDs is affected by the smaller entrance aperture. The 2D imaging LMD will have an entrance pupil between 2 mm to 5 mm. (See [1][1], [2] for the effect of aperture size.)

NOTE 2 Moiré effect might occur in the 2D imaging LMD due to factors such as pixel structure, rotational misalignment, etc. If moiré occurs, the measurement cannot be performed. (See [3] for more information about moiré.)

NOTE 3 The peripheral 2D luminance data of the 2D imaging LMD can include vignetting. The valid measurement field angle can include only 2D luminance data without such peripheral 2D luminance data.

5.2.2 Stage conditions

Stage conditions shall comply with IEC 63145-20-10 and IEC 63145-20-20.

5.2.3 Setup conditions

Setup conditions shall comply with IEC 63145-20-10 and IEC 63145-20-20.

[1] Numbers in square brackets refer to the Bibliography.

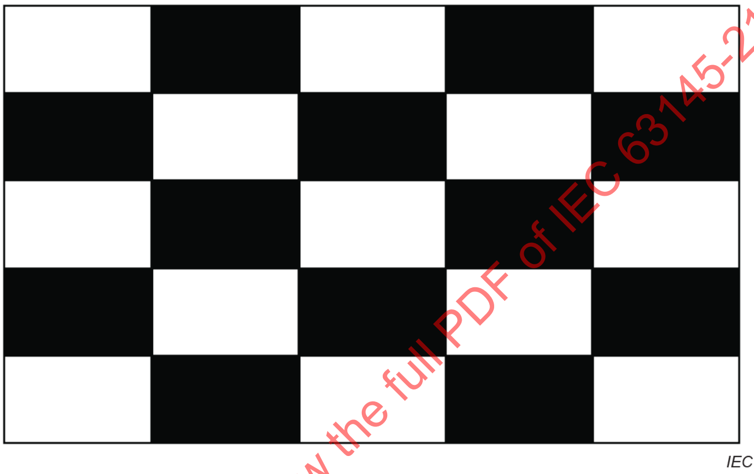
5.3 Test patterns

5.3.1 General

The following test patterns shall be specified, and the applied test pattern shall be noted in the report. When other test patterns are applied, they shall be noted in the report.

5.3.2 Checkerboard pattern

The checkerboard pattern as shown in Figure 1 should be used to measure the applicable properties and can be used for alignment of the DUT and LMD optics. The checkerboard pattern with crosses, whose example is specified in ISO 9241-305 [4], should also be used for alignment of the DUT and LMD optics. Both patterns of white and black at the centre can be used. Usually, a white and black checkerboard pattern is used, but a checkerboard pattern of another colour (red, green, blue and so on) and black can be used if necessary.



NOTE The 5 × 5 checkerboard pattern is helpful in navigating across the virtual image and focusing the LMD.

Figure 1 – Example of 5 × 5 checkerboard pattern

5.3.3 4 % colour window signal patterns

4 % colour window patterns can be used to measure the optical qualities. The colours should be defined in terms of the display primaries as white, black, red, green and blue. The 4% window is filled with a single colour. Figure 2 shows an example of a 4 % white window signal pattern that is surrounded by black background.

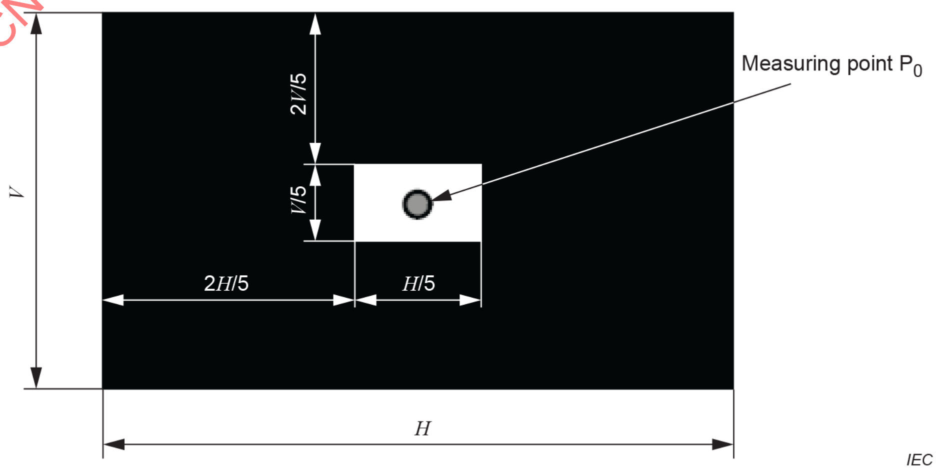


Figure 2 – Example of 4 % white window signal pattern

5.4 Measuring points

The centre point (one point) or the multi-point (five points or nine points) measurements shall be applied. An example of measuring point(s) of one-point, five-point, and nine-point measurements is P_0, P_0 to P_4, and P_0 to P_8, respectively, as shown in Figure 3, where H and V are used to define the positions of these points.

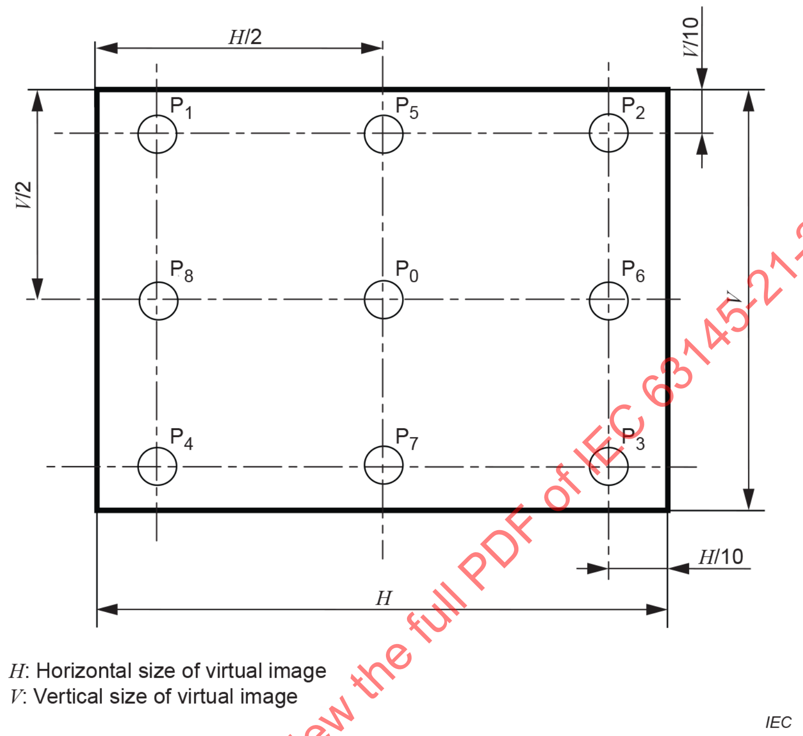


Figure 3 – Example of measuring points for the centre and multi-point measurements

Another example of nine points is shown in Figure 4, where azimuth and elevation angles are used to define the positions. Azimuth and elevation angles are defined in IEC 63145-20-10:2019, Figure 1.

If other measuring points are applied, this shall be defined in the relevant specification.

NOTE The centre point measurement is carried out to measure the screen door effect. The five-point and nine-point measurements are carried out to measure the deviations, averages, and uniformities.

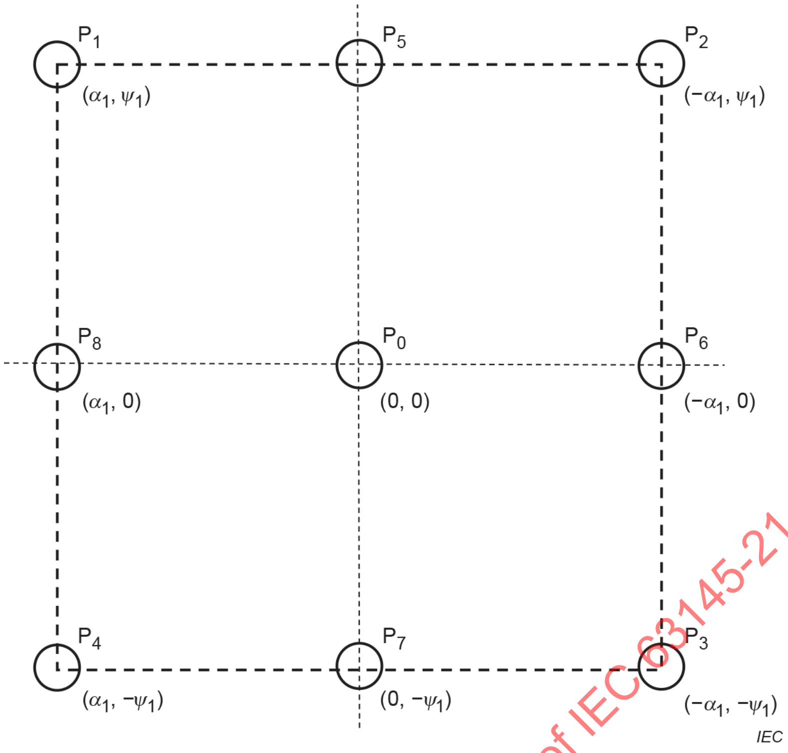


Figure 4 – Example of measuring points in azimuth and elevation angles

6 Measurement methods for screen door effect

6.1 General

The screen door effect (SDE) is one of the items for evaluating the image quality of the eyewear display to be measured (DUT). SDE is observed as the spatial repetition of the bright and dark region. The purpose of this method is to measure the screen door effect at the centre or the other measuring points (see Annex B).

The standard measurement conditions (Clause 4), the standard coordinate system (5.1), setup conditions (5.2.3) and 4 % window pattern (5.3.3) shall be applied.

6.2 Preparations

The DUT should be placed in the measurement arrangement specified in 5.2.3 using the checkerboard pattern specified in 5.3.2. The entrance pupil of the LMD and the eye point of the DUT shall match the origin position of the five-axis system (x = 0, y = 0, z = 0, α = 0, Ψ = 0).

NOTE In case the pivoting point of the LMD is 10 mm behind the entrance pupil, this pivoting point can be used, instead of the entrance pupil, to match the origin position of the measurement.

The DUT-adjustable conditions which are related to the optical properties shall be reported. Some DUTs use image processing, and if a setting for the image processing is also adjustable, the default setting specified by the manufacturer or the supplier shall be applied and reported.

The focus of the LMD shall be adjusted through the image finder or by a supplier-specified autofocus procedure to achieve the clear virtual image. A grille pattern with a high resolution (the highest resolution is a one-by-one line pair) which is appropriate for the DUT and provided by the manufacturer or the supplier, can be applied for adjustment of the virtual image focus.

The optical quantities at different measuring points (directions) should be measured at the steady state as specified in Clause 4.

6.3 Measurement procedures

To measure the screen door effect, the following procedures shall be used:

1) Position the DUT as specified in 5.2.3.
2) Display a checkerboard pattern with crosses.
3) Adjust the LMD to match the entrance pupil of the LMD at the eye point of the DUT and to be focused on the virtual image.
4) Align the LMD to the centre point P_0 of the virtual image.
5) Display the 4 % white window signal.
6) Measure the 2D luminance data using the LMD.
7) Repeat the same process for the other measuring points P_i of the virtual image. Index i is the index of the multi-point measurement (optional).
8) Repeat for the other ocular.

6.4 Calculation

1) From the measured 2D luminance data, determine the period p_{MWA} for the moving window average (MWA). Choose p_{MWA} to be equal to the detector pixel numbers that cover one arc minute.

   NOTE 1 For example, if the angular detector pixel size of the 2D imaging LMD is 0,1 arc minute, p_{MWA} is selected as 10.

2) Calculate the average 2D luminance data, by applying the moving window average (MWA) method to the measured 2D luminance data.

   NOTE 2 See IEC 62977-3-9:–, Annex A or Annex B [5] for more information and when p_{MWA} is a non-integer.

3) From the MWA converted data, select the section that includes more than 10 × 10 display pixels for the measuring point P_0 to obtain $L_{\mathrm{max}(m,\ k)}$ and $L_{\mathrm{min}(m,\ k)}$. Indexes m and k which are the numbers between 1 and 10, represent the position for horizontal and vertical display pixels, respectively.

   NOTE 3 See Annex A for the explanation on how to get the maximum and minimum luminance from 2D luminance data.

   NOTE 4 Among arrays of maximum luminance values of MWA, multiple sections of 10 × 10 can be selected. The standard deviation of 10 × 10 values of maximum luminance of these sections is calculated. The section of the smallest standard deviation is used as the data of $L_{\mathrm{max}(m,\ k)}$ and $L_{\mathrm{min}(m,\ k)}$.

   NOTE 5 The procedure is described for the rectangular subpixel layout. For a non rectangular layout, the 2D luminance data is rotated such that the positions of the maximum luminance are aligned horizontally and vertically. See [6] and Annex C for examples of pixel layout in which rotation of 2D luminance data cannot align the maximum luminance both horizontally and vertically. If the positions of the maximum luminance cannot be aligned horizontally and vertically even after rotating 2D luminance data, the procedure cannot be applied to evaluate the contrast modulation value.

4) Calculate the averaged horizontal maximum and minimum luminance ($\overline{L}_{\mathrm{max}}$ and $\overline{L}_{\mathrm{min}}$) for the measuring point P_0, using Formula (1) and Formula (2) at each value of k = 1, … , 10.

$$\overline{L}_{\mathrm{h,max},k} = \frac{\sum_{m=1}^{10} L_{\mathrm{max}(m,k)}}{10} \qquad (1)$$

where

$\overline{L}_{\text{h,max},k}$ is the averaged horizontal maximum luminance;

$L_{\max(m,k)}$ is the maximum luminance of the index (m, k).

$$\overline{L}_{\text{h,min},k} = \frac{\sum_{m=1}^{9} L_{\min(m,k)}}{9} \tag{2}$$

where

$\overline{L}_{\text{h,min},k}$ is the averaged horizontal minimum luminance;

$L_{\min(m,k)}$ is the minimum luminance of the index (m, k).

5) Calculate the averaged vertical maximum and minimum luminance ($L_{\max}$ and $L_{\min}$) for the measuring point P_0, using Formula (3) and Formula (4) at each value of m = 1, ..., 10.

$$\overline{L}_{\text{v,max},m} = \frac{\sum_{k=1}^{10} L_{\max(m,k)}}{10} \tag{3}$$

where

$\overline{L}_{\text{v,max},m}$ is the averaged vertical maximum luminance.

$$\overline{L}_{\text{v,min},m} = \frac{\sum_{k=1}^{9} L_{\min(m,k)}}{9} \tag{4}$$

where

$\overline{L}_{\text{v,min},m}$ is the averaged vertical minimum luminance.

6) Calculate the horizontal and vertical contrast modulation (CM) (also called Michelson contrast) for the measuring point P_0 using Formula (5).

$$CM_{\text{h},k} = \frac{\overline{L}_{\text{h,max},k} - \overline{L}_{\text{h,min},k}}{\overline{L}_{\text{h,max},k} + \overline{L}_{\text{h,min},k}}, \quad CM_{\text{v},m} = \frac{\overline{L}_{\text{v,max},m} - \overline{L}_{\text{v,min},m}}{\overline{L}_{\text{v,max},m} + \overline{L}_{\text{v,min},m}} \tag{5}$$

where

$CM_{\text{h},k}$ is the horizontal contrast modulation at each value of k = 1, ..., 10;

$CM_{\text{v},m}$ is the vertical contrast modulation at each value of m = 1, ..., 10.

NOTE 6 If an averaging method other than MWA is used, this will be reported.

NOTE 7 This measurement is sensitive to veiling glare in the 2D imaging LMD and will vary with each LMD and pixel structure of the DUT.

NOTE 8 CM that characterizes the relation of brightness and darkness, is employed to measure SDE.

7) Calculate the average of the horizontal and the vertical contrast modulation.

$$CM_{\text{h}} = \frac{\sum_{k=1}^{10} CM_{\text{h},k}}{10}, \quad CM_{\text{v}} = \frac{\sum_{m=1}^{10} CM_{\text{v},m}}{10} \tag{6}$$

where

CM_{h} is the averaged horizontal contrast modulation;

CM_{v} is the averaged vertical contrast modulation.

8) Calculate the SDE factor as $F_{\text{SDE}} = 1 - CM$ for each condition.

9) Calculate the horizontal angular period of modulation that is the angular distance between two horizontal maximums.

10) Calculate the horizontal angular width of the bright and dark area using the threshold value of the luminance average along the horizontal direction.

NOTE 9 Other threshold values can be used to determine the width of the dark and bright area.

11) Calculate the horizontal aspect ratio of the bright and dark area by dividing the angular width of the bright and dark area by the horizontal angular period of modulation.

12) Calculate the horizontal angular frequency that is the inverse of the horizontal angular period of modulation.

13) Repeat the process of 9) to 12) along the vertical direction.

14) Repeat the same process for other measuring points P_i (optional).

15) Repeat the same process for the other ocular.

6.5 Report

The following items should be reported (see Table 1):

- average horizontal and vertical maximum and minimum luminance and the contrast modulation at each measuring point P_i;
- period p_{MWA} selected to apply the moving window average (MWA);
- measurement field angle of the LMD;
- eye point, position of the z-axis;
- type of LMD and aperture size;
- horizontal and vertical angular period of modulation;
- horizontal and vertical aspect ratio of bright and dark area;
- correction methods for the measurement, if possible (optional).

NOTE 1 The period p_{MWA} which is selected for the moving window average (MWA) is reported, as the selection of this period can affect the result.

NOTE 2 The performance of SDE relates to not only CM but also other factors such as angular period of modulation, aspect ratio of bright and dark area. See Annex B for more information.

Table 1 – Example of report table

Measuring point:		**Ocular**	**Left/right**
Eye point:	**Position of z-axis**		
LMD	**(1) type:**	**(2) aperture size:**	**(3) field angle:**
Period p_{MWA}:	**Use of correction method (1) N (2) Y ( )**		
Horizontal angular period of modulation	(degree)	Vertical angular period of modulation	(degree)
Horizontal aspect ratio of bright and dark area	(degree, degree)	Vertical aspect ratio of bright and dark area	(degree, degree)
$CM_{h:}$	$F_{SDE,h}$:	CM_{v}:	$F_{SDE,v}$:

Annex A
(informative)

Moving window average (MWA)

MWA is one of the averaging methods by the low pass filtering of discrete values. In MWA, each raw data is replaced by the average of raw data in the range from $-p_{\mathrm{MWA}} / 2$ to $p_{\mathrm{MWA}} / 2$ as shown in Formula (A.1):

$$D_{\mathrm{C}}[i] = \sum_{j=i-\frac{p_{\mathrm{MWA}}}{2}}^{j=i+\frac{p_{\mathrm{MWA}}}{2}} \frac{D_{\mathrm{R}}[j]}{p_{\mathrm{MWA}}} \qquad \text{(A.1)}$$

where

$D_{\mathrm{C}}[i]$ is the MWA converted data of the i^{th} position;

$D_{\mathrm{R}}[j]$ is the original luminance data (raw data) of the j^{th} position;

p_{MWA} is the MWA period (number).

Index i represents the i^{th} position of the original luminance data array. For each index i, raw data in the index range ($i - p_{\mathrm{MWA}} / 2$, $i + p_{\mathrm{MWA}} / 2$) are averaged and the averaged value is used as MWA converted data at index i.

```
1) Read 2 dim data and normalize 2 dim data,
     Read 2 dim data and find MAX value of 2 dim data.
     Lum_xy = 2-dim data where original data are divided by Max.
2) Read the horizontal and vertical size of luminance data
     y_SampleCount = vertical size of Lum_xy;
     x_SampleCount = horizontal size of Lum_xy;
3) Select P_MWA value from the measurement data
     P1 = largest integer small than P_MWA
     k  = largest odd integer smaller than P_MWA
     km = k + 2  =  smallest odd integer larger than P_MWA
     alpha = (P_MWA -k)/2 = non-integer part of P_MWA
     ( ex. when P_MWA = 8,4,    p1 = 8, k = 7, km = 9,  alpha = 0,7  )
4) Define MWA_M that is weight matrix of MWA of km by km size
     MWA_w =    (km-2)^2 +4*(km-2)*alpha + 4*alpha^2 ;
     MWA_M(1:km,1:km) = 1/MWA_w;
     MWA_M(1,1) = alpha^2/MWA_w;  MWA_M(km,km) = MWA_M(1,1);
     MWA_M(1,km) = MWA_M(1,1);   MWA_M(km,1) = MWA_M(1,1);
     From sfn = 2 to km-1
          MWA_M(1,sfn) = alpha/MWA_w;  MWA_M(km,sfn) = alpha/MWA_w;
          MWA_M(sfn,1) = alpha/MWA_w; MWA_M(sfn,km) = alpha/MWA_w;
     end
5) Do 2-dimensional MWA conversion by multiplying 2-dim data and MWA_M
     km_2 = round( (km-1)/2 );
     From yy = 1+km_2 to y_SampleCount - km_2
       From xx = 1+km_2 to x_SampleCount - km_2
             sum0 = 0;
          RawData_o = LumN_xy( yy-km_2:yy+km_2, xx-km_2:xx+km_2 );
          From yk =1 to km
               % Summation of each component of RawData and MWA M matrix
```

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NOTE The code is provided as-is and is not guaranteed to suit all purposes of users.

Figure A.1 – Example of pseudo code of MWA

The code in Figure A.1 is an example of a pseudo code which consists of the following parts.

a) Read the luminance data of the 2D matrix and do the normalization that all values of the original 2D luminance data are divided by the maximum value of the original 2D luminance data.

b) Read the horizontal and vertical size of the luminance data.

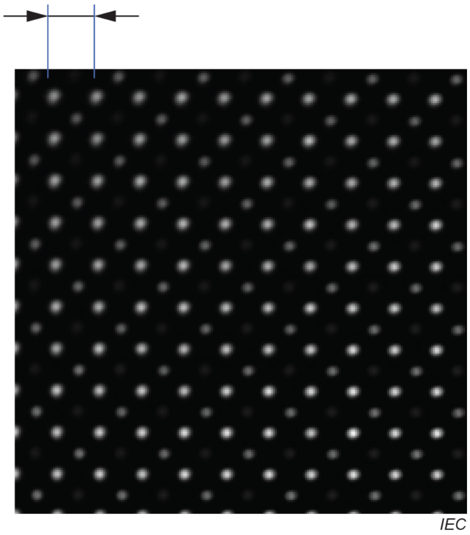
c) Select the p_{MWA} value. The value is selected as equivalent to one arc minute.

d) Define the weight matrix of the MWA in consideration of the non-integer part of P_MWA.

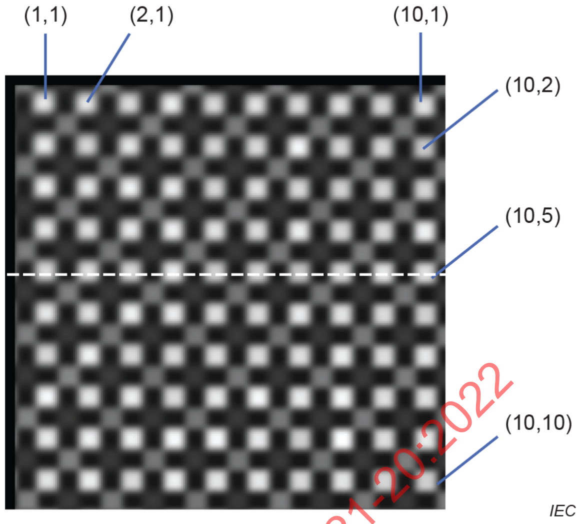
   NOTE See IEC 62977-3-9:–, Annex B, [5] for more information on the calculation when P_MWA is a non-integer.

e) Do the MWA conversion along the horizontal and vertical direction using Formula (A.1).

When the 4 % white window pattern is applied, the measured 2D luminance data show the periodic distribution which depends on the subpixel and pixel configuration of the display as shown in the example of Figure A.2a). Figure A.2b) shows an example of MWA conversion of 2D luminance data (image). In the example, p_{MWA} is selected to be approximately half of P_{DUT} (the number of detector pixel numbers that covers the pixel size of the DUT) for MWA conversion. The brightness areas are noted in indices (m, k). Indices m and k which are the number between 1 and 10, represent the position for horizontal and vertical pixels, respectively.



a) Original 2D luminance data



b) Data after MWA conversion (p_{MWA} / P_{DUT} ≈ 0,5)

Figure A.2 – Example of MWA conversion of 2D luminance data (image)

Figure A.3 shows the horizontal cross section of Figure A.2. The horizontal cross section is selected to pass through the brightest areas from index (1,5) to (10,5) in Figure A.2. The maximum luminance from index (1,5) to (10,5) is obtained from the ten peaks in Figure A.3. The minimum luminance from index (1,5) to (9,5) is obtained from the lowest value between the adjacent two peaks. Figure A.3 also shows the effect of the value of p_{MWA} in MWA conversion. When DUT pixel size is much larger than one arc minute, p_{MWA} / P_{DUT} is much smaller than 1 and MWA conversion only slightly changes the original data. When DUT pixel size is comparable to one arc minute, p_{MWA} / P_{DUT} approaches 1 and the difference between maximum and minimum luminance decreases.

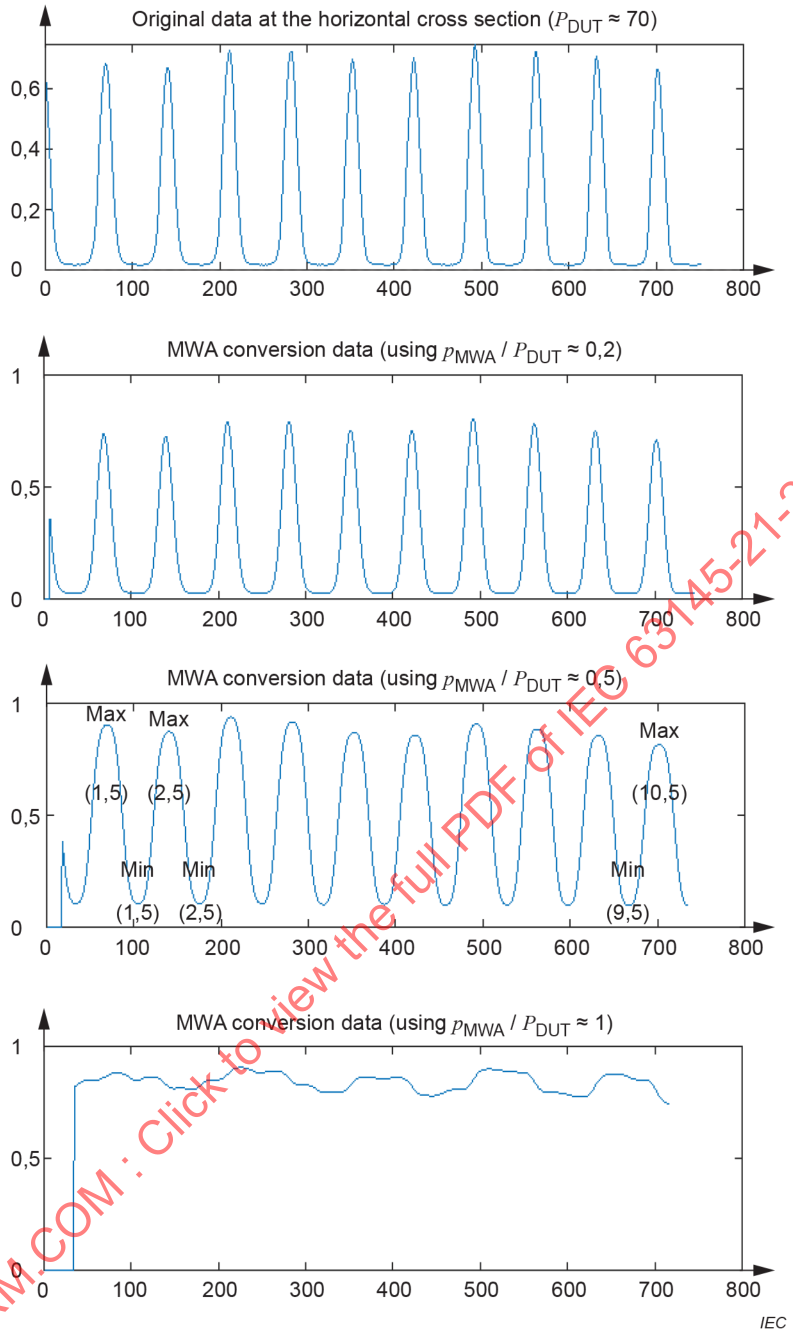


Figure A.3 – Example of the horizontal cross section