Standard of the Camera & Imaging Products Association

CIPA DC-003-Translation-2020

Resolution Measurement Methods for Digital Cameras

This translation has been made based on the original Standard (CIPA DC-003-2020).
In the event of any doubts arising as the contents, the original Standard is to be the final authority.

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Table of Contents

Introduction

This standard is the revised 2nd edition of the CIPA DC-003 Resolution Measurement Methods of Digital Cameras, which was 1st published in 2003. (The purpose and background of the enactment at the time of the 1st edition is described in detail in Explanations 1 and 2.) It has been a long time since the 1st edition was issued and the revision of the international standard ISO 12233, with which this standard has consistency, has caused the noticeable differences between the two standards, so the revision has become needed.

ISO12233 was titled “Resolution measurement” in the 1st edition issued in 2000 but it has been renamed “Resolution and spatial frequency responses” in the 2nd edition and later, which defines total three of the measurement methods: VR (Visual resolution measurement) as the resolution measurement method, and two SFR (Spatial frequency response) measurement methods of e-SFR (Edge-based spatial frequency response measurement) and s-SFR (Sine-based spatial frequency response measurement).

As a method of measuring resolution, VR is fundamental. A method of obtaining a spatial frequency value corresponding to a certain amplitude level using the measurement result of the SFR curve is also described, but this is only allowed when the correlation with VR can be obtained (because the SFRs have possibilities to produce different results from the human vision depending on the conditions).

Because of the above reason, this standard that specifies the resolution measurement method adopts the Visual resolution measurement specified in Chapter 5 of ISO12233: 2017 (3rd edition) and excludes two SFR measurement methods in ISO12233.

Regarding the relationship between this standard and the Visual resolution measurement described in Chapter 5 of ISO12233: 2017 (3rd edition), the described content of the 1st edition of this standard and the results of CIPA activities after the enactment of the1st edition such as the improved versions of the chart and the software were incorporated in the revision of ISO 12233. Thus the consistency between the two standards is bidirectional.

Note: SFR (spatial frequency response) is a measure of the relative amplitude response of an imaging system indicated as a function of the input spatial frequency. It is typically represented by a curve of a graph of the output amplitude response to a sinusoidal spatial luminance distribution input of constant amplitude over a range of spatial frequencies, drawn with normalizing so that a value of the output amplitude is 1 at a spatial frequency of 0.

Revision history

Dec., 2003 1st edition	CIPA DC-003-2003	Specified resolution measurement methods for digital cameras
Sep.,2020 Revised 2nd edition	CIPA DC-003-2020	▸Revised the description of [Introduction] ▸Updated [2. Normative reference] ▸Revised the description of and added a term to [3. Terms and definitions] ▸Updated [4. Test chart] due to the new chart ▸Updated [5. Test Conditions] - Detailed [5.2 Framing] - Added a provision to [5.4 Exposure settings] ▸Added a new item [6.1.1 Image presentation conditions] to [6. Measurement condition] ▸Updated [7. Notation of Resolution] - Arranged perfectly to be consistent with ISO 12233: 2017 (except for the added provisions of CIPA) - Added provisions on numeric rounding to [7.1 Numerical value of resolution] ▸Added example.6 to [8. Examples of Notations] ▸Former [9. Notes on ISO12233] is deleted ▸Editorial correction for overall - Error corrections, and improvement and unification for expressions and appearances

1. Scope

The CIPA Standard DC-003(2003) (hereinafter called "this standard") is applicable to consumer digital still cameras (DSC). It specifies a standard measurement procedure to be used when reporting still image resolution in advertising including catalogs.

2. Normative References

The following normative documents contain provisions which, through reference in this text, constitute provisions of this standard.

ISO12233:2017 Photography - Electronic still-picture cameras - Resolution and spatial frequency responses

ISO7589: 2002 Photography - Illuminants for sensitometry - Specifications for daylight, incandescent tungsten and printer

3. Terms and Definitions

3.1 resolution:

Ability of a camera imaging to resolve (reproduce) detailed patterns while false resolutions caused by aliasing are excluded. The fineness of the patterns is expressed as the number of lines per picture height, that is, the spatial frequency value in the unit [LW/PH].

Note: Sometimes supplementary expression such as “Imaging resolution” or “Camera resolution” is used to distinguish because also the pixel number of a monitor (display) and the dot number of scanner sampling or a printer are called “resolution”.

3.1.1 visual resolution:

Resolution evaluation method using the visual resolution estimating pattern so-called wedge, where the resolution is decided as a spatial frequency at which all of the individual black and white lines of a captured image (reproduced on a monitor or a print) can no longer be distinguished by a human observer. Also a resolution value measured by this evaluation method.

Note: Though the value evaluated by visual resolution is “resolution” from the definition, it is also called “visual resolution” in the context to be clarified or emphasized as the evaluation method.

3.1.2 limiting resolution:

(1) Resolution evaluation method formerly described in ISO 12233:2000(The 1st edition) as such, after measuring the signal amplitude of a captured image of a limiting resolution evaluation pattern called “frequency sweep image” as a function of spatial frequency, a resolution value is obtained as the spatial frequency value corresponding to the point at which the amplitude decreases to a certain value. It was deleted in the 2nd edition and later because of the instability derived from aliasing effects.

(2) Sometimes used as another name of resolution defined in 3.1. As mentioned in the note of 3.1, since there are customs to call the number or density of pixels or dots corresponding to spatial frequency “resolution”, it is understandable as the “limit” of that. However it is better to avoid confusion derived from using another name at digital camera evaluation including this standard.

Note: About “resolution limit”: there are some cases in this standard to use “resolution limit” depending on the context of explanations. It is not a technical term with definition, but a general expression meaning “limit of resolving” that is “limit of obtaining resolution (reproduction of fine patterns)” or such.

3.2 aliasing:

Output image artefacts (pseud pattern images not existing in the original object) that occur in a sampled imaging system due to insufficient sampling. These artefacts usually manifest themselves as moiré patterns in repetitive image features or as jagged stair-stepping at edge transitions.

3.3 spatial frequency:

Fineness (coarse and dense) of the wave represented by the number of repetitions of the wave per unit length, when a light-dark repetition distribution such that white and black lines are alternately arranged is regarded as a brightness wave. A larger value corresponds to a finer pattern. As a reference unit length, there are cases where an absolute value (such as 1 mm) is used and a case where a relative value (such as the screen height) is used. While the number of repetitions uses the number of white and black lines, there are a case where one black and white pair is counted as one, and a case where black and white are counted one by one as total two.

3.4 LW/PH

line width per picture height**:** A relative spatial frequency unit using the active screen height (Picture Height) as the reference unit length and counting the repetition as two for one pair of black and white. The active screen is an active image area (field of view range) of the light receiving surface of the image sensor when taking an image with a camera, and corresponds to the active image area of the monitor screen when outputted to a monitor.

Note 1: For example, if there is a so-called VGA image of 640 dots (horizontal) x 480 dots (vertical) of black and white horizontal stripe images, of which the black and white horizontal lines are alternately black and white corresponding to 480 vertical dots (that is 480 horizontal lines consist of 240 white lines and 240 black lines), since the total number of black and white lines is 480, the image has a spatial frequency of 480 LW/PH. (The numerical value is equal to the ratio PH/LW obtained by dividing the screen height PH by the line width LW when the white line and the black line have the same width.)

Note 2: In the example of Note 1, each line number of black and white is described as "line". This is also expressed as "line (s)" in English and "[hon]" (meaning the number of lines) in Japanese. The definition of the unit LW/PH is equivalent to the relative spatial frequency unit "TV lines" used in the television field, and is a redefined term in ISO 12233 as a unit system that does not use "TV". For this reason, in general situations other than official use, such as described in catalogs, there are cases that "hon", "number of lines" or "lines" is used as abbreviations.

Note 3: In an optical system such as a taking lens, an absolute spatial frequency using a reference unit length of 1 mm is used. Note that one cycle of a wave is counted as one (1 line), so the wave counted as 480 in the example in Note 1 is counted as 240. Units such as "cycles/mm", "[hon]/mm" and "lines/mm" are used, but it is also necessary to be noted that if "/mm" is omitted as an abbreviation, it cannot be distinguished from the abbreviation of "LW/PH".

4. Test Charts

4.1 ISO 12233 compliant CIPA resolution chart

This standard is based on the ISO12233, then the CIPA resolution chart (**Fig. 4.1**) described in ISO 12233:2017 should be used as the test chart. The CIPA resolution chart contains a variety of patterns, but for the visual resolution measurements in this standard, 4 hyperbolic wedge patterns shown by symbol J (as a breakdown, j1 to j4 that are not described in the ISO standard are also added) are to be used.

The CIPA resolution chart does not have to be used in its entirety; the relevant patterns may be extracted and rearranged if under the condition that the photographing magnitude is the same as the original usage (See also 5.2 Framing).

Note: Where to get charts

See the CIPA web page for obtaining this chart (URL is as of the 2nd edition)

http://www.cipa.jp/dcs/hyres/chart_e.html

4.2 Meaning of numbers on the ISO chart

The CIPA resolution chart is designed so that when the active height (the vertical distance inside the black border of **Fig. 4.1** viewed lengthwise) fills the vertical picture height, spatial frequency in the unit [LW/PH] is the number on the pattern times 100. It is not an absolute requirement to fill the entire picture height with the chart, but calibration of the results is necessary when this is not done (see **5.2 Framing**).

4.3 Use of charts other than the CIPA resolution chart

The CIPA resolution chart is recommended to be used because it is an improvement of the old resolution chart described in the first edition of ISO 12233 (issued in 2000). But also the old chart, where its specifications are still described in Annex I of ISO 12233: 2017, may be used.

A chart similar to these ISO charts may be created and used. In that case it shall meet the following conditions a, b and c according to 5.2.5 and 5.2.6 of ISO12233:2017. If the condition a is not able to meet, it shall be indicated.

a) The ratio of the maximum chart reflectance Rmax and the minimum chart reflectance Rmin for large test pattern areas should be not less than 40:1 and not greater than 80:1 (40 < Rmax/Rmin <80) [Recommendation]

b) The positional tolerance shall be such that all test chart features are accurately located to within 0.2 mm, or ±0.1% of the active height. [Requirement]

c) The line width tolerance shall be within ±5% [Requirement]

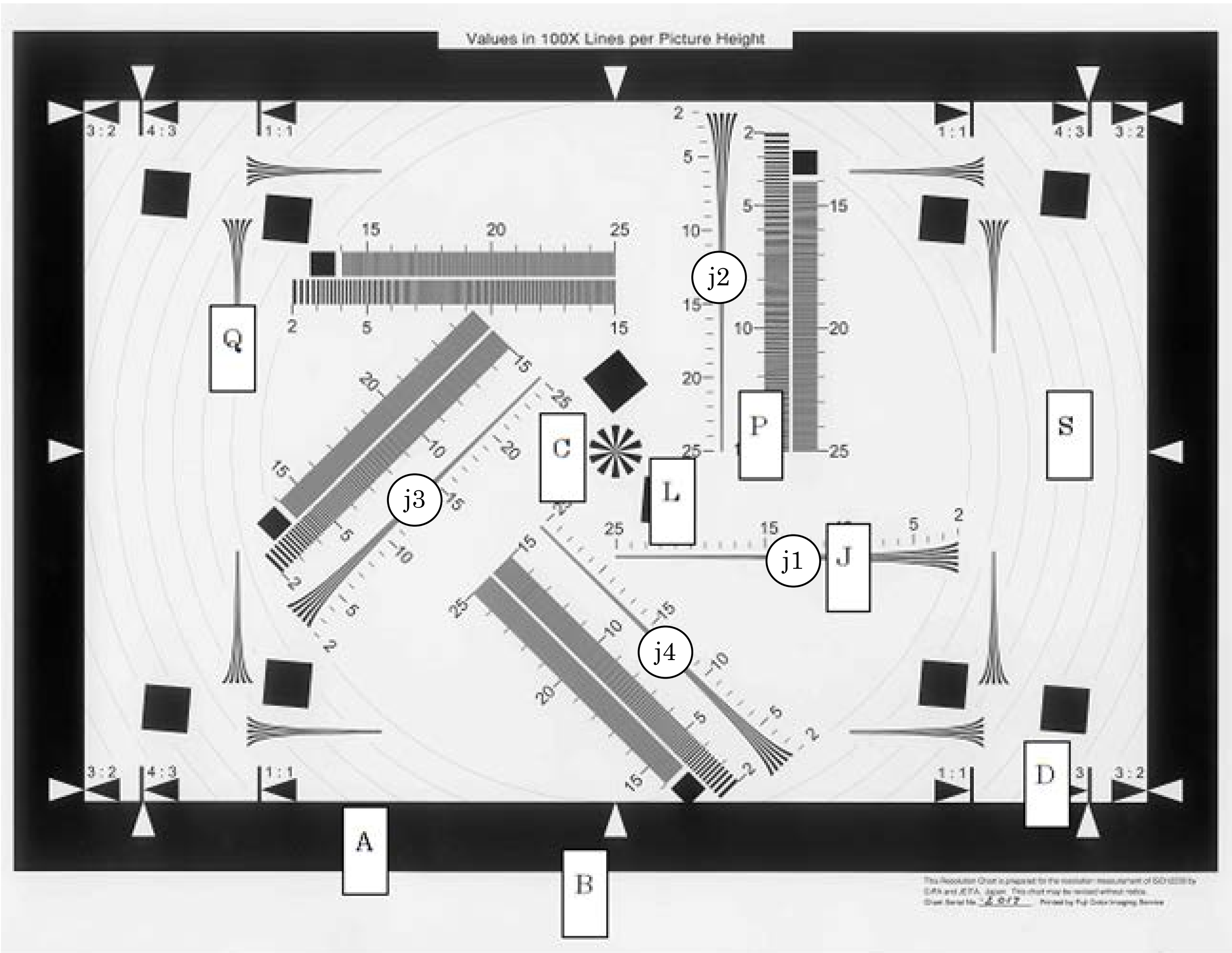
Furthermore, the ratio of “reflectance ratios for the finer test chart features” to “reflectance ratios for large test pattern areas”, should preferably be reported by the chart manufacturer for reference. The reflectance ratio Rmax/Rmin for the finest features of hyperbolic wedges J and Q of the CIPA resolution chart should be 18 or above as shown in the Annex a.2 of ISO 12233:2017.

Use of a transparency chart is allowed, in which case "reflectance" above is to be understood as "transmittance." When a transparency chart is used, it shall be rear illuminated by a diffuse source.

Whether a reflection chart or transparency chart is used, the patterns used for evaluation shall be spectrally neutral.

In addition, as described above the spatial frequency scale of the CIPA/ISO resolution chart is [LW / PH] unit, that is, a relative numerical value, thus the same measurement can be performed even when any similar deformation (enlargement/reduction) is applied.

Fig.4.1 CIPA resolution chart



5. Test Conditions

5.1 Test chart illumination

The chart shall be illuminated by either the daylight (default) or tungsten illuminants specified in ISO 7589. The luminance of the test chart shall be sufficient to provide an acceptable camera output signal level. The luminance of any area of the chart shall be within ±10% of the average luminance near the center of the chart. Care should be taken to prevent direct illumination of the camera lens by the illumination sources. The area surrounding the test chart should be of low reflectance, to minimize the influence of flare light.

5.2 Framing

The chart shall be oriented parallel to the focal plane of the camera and its horizontal edge is parallel to the horizontal frame line of the camera. ISO12233 stipulates that the active height of the chart (the height of the area inside the black border in Fig. 4.1) should fill the picture fully. This defines the photographing magnification of the chart, and it is natural that this state is the basis, but even if the photographing magnification is different, it is possible to obtain the correct measurement value by converting the magnification and correcting the numerical value. Therefore, in the case where it is difficult to take an image with the prescribed framing (depending on the focal length / focusing distance of the taking lens, the size of the experimental environment, etc.), the image may be taken larger or smaller.

The correction of the magnification may be performed by multiplying the value read on the scale of the chart by the reciprocal of the relative magnification with respect to the specified magnification. When the image is taken at a lower magnification than specified, it is easy to multiply “[the number of vertical pixels of the full screen]/[the number of pixels corresponding to the active height of the chart in the screen]”. If a large image is taken, this method cannot be used because the active height of the chart exceeds the shooting range, so multiplying by "[the number of vertical pixels of the full screen]/[the number of pixels corresponding to the length of the wedge in the screen] x [the length of the wedge]/[the active height of the chart]" is used. This conversion is also effective when cutting out the wedge of the chart described in 4.1.

Note 1: While it is known that the optical performance greatly changes depending on the shooting distance, this standard does not specify the shooting distance, but enables measurement at a desired distance. However, it is important to note that using the CIPA resolution chart as it is can result in a much shorter shooting distance that is different from the distance assumed by many general photographic lenses. In other words, there can be a case where it is desired to increase the shooting distance, and an enlarged CIPA resolution chart is usable for the case.

As mentioned in 4.3 of this standard, since relative spatial frequency is the measurement target, the same measurement can be performed using a similar enlarged chart. Here it will be explained from the framing standpoint. If the M-times enlarged chart is photographed so that the active height fills the screen, the photographing distance can be increased by M times. In the M-times chart, the absolute spatial frequency is 1/M of the CIPA resolution chart, but at the same time, the photographing magnification is 1/M times the specified magnification as using the CIPA resolution chart. Thus M is multiplied in the framing magnification conversion above, resulting in the spatial frequency value of the scale of the chart being able to be applied as it is.

However, it is necessary to note that an extremely large size makes it difficult to illuminate uniformly especially in a reflection chart.

Note 2: Although this standard does not specify the measurement position on the screen, one example if measuring the peripheral resolution is as follows. The wedges are placed on the intersection of a concentric circle whose radius is the relative image height (percentage) from the center (where the image height of the outermost periphery in the screen is 100%) and a diagonal of the screen.

5.3 Rules for setting camera conditions

Resolution measurement in accordance with this standard shall as a rule use the default camera parameters which have been selected at delivery. If any camera parameter other than the default settings is applied for resolution measurement, it shall be properly indicated. When any parameter cannot be definitely determined by the default settings, measurement shall be made based on the settings which the camera maker supposes the users are most likely to use, and the appropriate information shall be included to allow identification of the selected settings.

Description and examples: The above rule for selecting the default settings for resolution measurement is based on the assumption that the default settings are adopted by individual makers as to be the most likely to be used by the users for given models.

In practice, however, default settings may not determine the measurement conditions in some cases, such as when "off" is selected by default in a camera designed with a function selector dial serving also as the on/off switch, which allows switching of functions in the order of "off → playback → standard quality image → uncompressed image." In this case, measurement shall be made based on the conditions (e.g., standard quality image) the makers anticipate the camera users are most likely to use, and the relevant information shall be included to help identify the selected settings.

5.4 Exposure settings

Not specified, except that the settings shall not result in signal clipping in either the white or black areas of the test chart, or regions of edge transitions.

5.5 Focusing

Not specified.

5.6 White balance

The camera shall be adjusted to provide proper white balance for the illumination light source.

5.7 Zoom position

Not specified.

6. Measurement Conditions

DSC resolution is evaluated by photographing the test chart described above and viewing (visually observing) it either on a monitor or as a hard-copy printout. Evaluation using software that performs the equivalent processing as visual evaluation may also be available.

6.1 Evaluation by a visual observation

6.1.1 Image presentation conditions

The print or monitor display magnification shall be "pixel equal size" (a state where the pixels correspond as one-to-one), and the pixels shall not be resampled. The setting of the device to be used (the setting of the device driver when via a computer) is set so that the number of pixels of the active print area of the paper or the active display screen of the monitor is maximized.

And when observing this, it shall be presented so that the resolution of the human vision is not lower than the print or monitor display presentation resolution (pixel density).

Note 1: The basic idea of this rule is to measure under evaluation conditions that can sufficiently exert the resolution performance of the camera, and it is not allowed to reinforce the resolution performance beyond the ability due to the evaluation environment. Therefore, attention is required so that special image processing such as super-resolution processing is not performed on the device to be used.

Note 2: The setting of the number of pixels in the devices above is often called as "resolution" (see note in 3.1). In a printer, it is associated with the pixel density indicated by the unit “ppi”, and is different from the dot density indicated by the unit “dpi”.

Note 3: Assumed resolution of the human vision is visual acuity of 1 (view angle of 1 minute). For example, when observing at a distance of 50 cm, the resolution corresponding to a visual acuity of 1 is 145.4 μm (6.88 pixels/mm = approx. 175 ppi). For example, in the case of a 4K equivalent vertical 2160 pixel monitor, the active height of the screen is 31.4 cm (approx. 26 inches) or more. Even if it is smaller than this, it is usually not a problem because the observation distance is able to shortened, but note that if the screen is small like a smartphone, there is a possibility not to satisfy the conditions able to be observed with the naked eye when the number of pixels becomes extremely high.

6.1.2 Evaluation criteria of visual observation judgement

Evaluations shall be made as following two criteria to minimize variations.

a) The measured resolution shall be the spatial frequency at which the number of visible wedge lines on a visual resolution test pattern changes from the original number (such as, from 5 to 4).

b) Observations shall always be made from lower to higher spatial frequencies.

6.2 Measurement by software

Visual resolution evaluation can be made by either of the methods described in **6.1**. However, while these methods are relatively simple, they suffer from a number of disadvantages, such as (i) individual differences among evaluators, (ii) lack of guaranteed reproducibility, and (iii) the influence of the monitor or printer used for output. To overcome the lack of guaranteed reproducibility and device-dependency problems, it is therefore allowable to use computer software to perform the same kind of processing as in the visual resolution measurements.

Note: Use of computer software for resolution measurement was proposed by one of the members during the course of the procedures for establishing this standard. The supplied software HYRes was tested by individual members (10 in total) with the results in good agreement with the visual measurement results, and then it was included in this standard. (The operating principle of the software HYRes is outlined in Annex 1, the algorithm used in the software is detailed in Annex 2 and Annex 3, and the test results are summarized in Annex 4.)
HYRes is updated after that and the latest version is available from the CIPA web site:
http://www.cipa.jp/dcs/hyres/hyres_dl_e.html
Users may create and use their own similar programs.

7. Notation of Resolution

Notation of resolution shall follow the rules specified below for all purposes including explanation and advertising media. Items described in **7.2** through **7.4** shall be always included in the list of specifications, list of performances, and other information blocks when these blocks report the resolution.

7.1 Numerical value of resolution

Notation of resolution shall include only the resolution measured in the conditions specified by the method in accordance with the CIPA Standard for Resolution Measurement Methods. The unit [LW/PH] shall be used. And when rounding numeric values, round down shall be used.
Any resolution exceeding 600 LW/PH should be noted in units of 50 LW/PH. The reason of 50 LW/PH is described in Annex 4.

7.2 Resolution measuring direction

There are four directions for measurement of resolution, (1) horizontal, (2) vertical, (3) 45-degree diagonal to the upper right, and (4) 45-degree diagonal to the lower right. (For "45-degree diagonal" different values can be resulted between diagonal to the upper right and diagonal to the lower right.)
The manner of presentation shall be selected by following two.

(1) Basic presentation

The resolution value of each measuring direction shall be reported with its direction for all measured directions.

(2) Representative presentation

The minimum resolution value for all measured directions shall be reported without its direction.

The average resolution value can be reported as a representative value additionally if each of the minimum (with its direction, mentioned above) and average is clearly specified.

For simplicity, "45-degree diagonal to the upper right" may be expressed as "diagonal to the upper right" and "45-degree diagonal to the lower right" as "diagonal to the lower right."

7.3 Resolution measurement method

a) **General rule**: Resolution measurement methods shall be noted as "based on the CIPA Standard," "in accordance with CIPA," or simply "CIPA" similarly as in the cases of exposure conditions, test charts, and measurement methods.

b) **Exception**: Notation of resolution measurement method may be omitted when the fact that the resolution has been measured by an appropriate method based on the CIPA specified resolution measurement methods is indicated in the same explanation/advertising media reporting the resolution or in any other independent media.

In addition, "CIPA" may be omitted when indicated the compliance with ISO 12233: 2017.

7.4 Camera settings

When resolution is measured with any camera parameter settings other than the default settings, these settings shall be indicated adjacent to the notation of resolution. (See **5.3 Rules for setting camera conditions**.)

7.5 Measurement conditions

Measurement conditions may include the means used for the measurement, hard-copy printout, monitor, or software. In this case, the means shall be noted adjacent to the notation of resolution. (See **6. Measurement Conditions**.)

Where the purpose is not limited to specification value notation in catalogs as such, for example performance reports, the means used shall be necessarily indicated.

8. Examples of Notations

Examples of **notation of resolution** are listed below for the following values: 1250 [LW/PH] of horizontal resolution, 1200 [LW/PH] of vertical resolution, 1150 [LW/PH] of 45-degree diagonal to the upper right resolution, and 1100 [LW/PH] of 45-degree diagonal to the lower right resolution.

Example 1) Notation of only the smallest value (representative value)
Resolution: 1100 [LW/PH] (in accordance with CIPA)

Example 2) Notation of the smallest values (representative value), added with the average value in units of 50 LW/PH
Resolution: 1100 [LW/PH] (diagonal to the lower right), the average value 1150 [LW/PH] (based on the CIPA Standard)

Example 3) Notation of the smallest value, added with the average value without rounding
Resolution: 1100 [LW/PH] (diagonal to the lower right), the average value 1175 [LW/PH] (CIPA)

Example 4) Notation of all values
Resolution: Horizontal 1250 [LW/PH], vertical 1200 [LW/PH], diagonal to the upper right 1150 [LW/PH], diagonal to the lower right 1100 [LW/PH] (based on ISO 12233:2017; Evaluated on a monitor)

Example 5) Notation of added camera settings
Resolution: 1100 [LW/PH] (in the case of RAW recording, in other cases based on the CIPA Standard; Evaluated by a software)

Example 6) Notation of added peripheral resolution (where the minimum value is 1000 [LW / PH]) in the case of Example 1
Central resolution: 1100 [LW/PH],
Peripheral resolution (at 80% image height): 1000 [LW/PH]
(in accordance with CIPA, evaluated on a print)

Annex 1 (Informative) Outline of the resolution evaluation software HYRes

This annex describes the outline of the software HYRes. (The algorithm is detailed in Annex 2.)

1. Preprocessing: Selecting the region of interest

The HYRes supports BMP and JPEG file format. Any image data recorded by any format other than these formats must be formatted in advance before processing by the appropriate image processing software to accommodate the BMP file format. Then, the image file is read out by the HYRes and the area of interest including evaluation pattern for visual resolution is cut out. The HYRes performs the processing by setting the data in such an orientation that the main scanning direction intersects the wedge as shown in Fig. 1 in Annex 1. When the vertical or 45-degree diagonal wedge is cut out, the HYRes automatically identifies the data and rotates it for calculation. Since 45-degree rotation could affect resolution measurement depending on the method used, following two principle requirements are adopted:

a) To eliminate pixel-resampling in order to prevent possible missing of information.
b) To adopt pre-interpolation: When producing a new pixel by means of interpolation, pixels between white and black areas will become gray when both areas are averaged. Producing such a color not existing originally can adversely affect the measurement of resolution, therefore, pre-interpolation is adopted.

The 45-degree rotation algorithm based on the above two requirements is described in Annex 3.

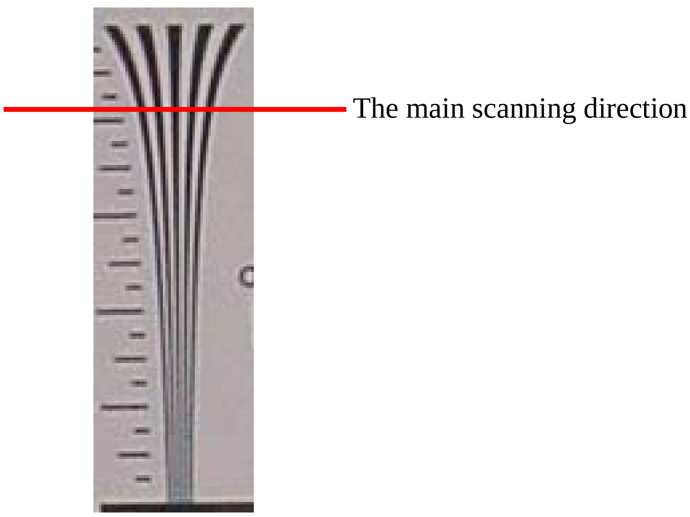


Fig. 1 in Annex 1

2. Main processing: detection of wedge line change

Visual evaluation using the HYRes software is performed as follows.

a) The measured resolution shall be the spatial frequency at which individual black and white wedge lines on a visual resolution test pattern can no longer be distinguished (e.g., the number of visible lines changes from 5 to 4, etc.). The result shall be expressed as the number of lines per picture height [LW/PH].

b) Observations shall always be made from lower to higher spatial frequencies.

Both of these are performed in the software, as explained below with reference to Fig. 1 in Annex 1.

The number of wedge lines (5 or 9) in the extracted image is required for the calculations, so this parameter is entered manually before proceeding.

First the wedge starting line is detected. In preprocessing, the image was extracted so that the horizontal plane intersects the wedge lines as in Fig. 1 in Annex 1, so the image is scanned horizontally from the top to detect wedge starting line WSL. In reading one line, three smallest values are selected and the start of the wedge is considered to have been detected when the difference between the average of those three values and the average value of all points on the line is five times that of the first line.

The wedge lines are counted by continuing the scan and detecting the maximum and minimum values of each line. The influence of noise and undulation is excluded by ignoring changes below a certain threshold. The initial threshold is 1/4 the difference between the average value of all points on one line and the average of the three points with the smallest values. If detection with the initial threshold cannot be made as the scan proceeds to the high-frequency end, the threshold is gradually reduced as the detection process is repeated until it succeeds. In this way the minimum and maximum values are counted. When the number of black lines counted in this way no longer matches the number entered manually at the start of the procedure, that line is the resolution limit line LML.

Scanning is then continued to find the end line of the wedge pattern WEL. This decision is made by determining the line width of each line and detecting when a steep reduction occurs compared to the previous line width.

3. Calculating process

Finally resolution is calculated based on WSL, LML, and WEL. The ISO chart is a so-called linear sweep chart, on which the spatial frequency of the visual resolution pattern changes linearly as it is scanned lengthwise. This length is 0.3 times the length of the active height (20cm), or 6 cm. Although the ISO chart was designed so that its active height should fill the picture fully, this is not an absolute requirement. If the chart does not fill the picture height, resolution can still be calculated using the ratio of the total picture height PHT to the wedge length (WEL- WSL) and the compensation factor C.

In the case of a 5-line wedge, this is:

Resolution = (100 + 500 × (LML - WSL) / (WEL - WSL)) × C ‥ (1-1),

and in the case of a 9-line wedge, it is:

Resolution = (500 + 1500 × (LML - WSL) / (WEL - WSL)) × C ··· (1-2)

Here compensation factor C is calculated as follows:

C = 0.3 × PHT / (WEL - WSL) ··· (1-3)

Note: About calculating process and charts

Understandable with the explanation above, since the calculation uses the active height, the wedge length and the respective frequencies (100, 500 and 1500) of start and end points of the wedge, it depends on the chart specifications applied. Values in equations (1-1)-(1-3) correspond to the old ISO 12233 chart (ISO12233:2000), and those of the CIPA chart are different.

Annex 2 (Informative) Description of HYRes Limiting Resolution Evaluation Algorithm

Note that "lines" or "number of lines" is sometimes used as an abbreviating expression of "LW/PH" in this annex.

1. Introduction

Software for analysis of image data is used independently from output devices and individuals evaluators, and thus it is naturally expected to provide results of higher reproducibility. In practice, however, it is imperative to ensure proper correlation with the traditional, proven method namely the visual resolution measurement method (visual evaluation).

When the results based on the software method are believed to provide the information limits of image data that could not be reproduced further even with any output device, they must be equivalent to the results obtained from the visual evaluation using an output device of appropriate capability.

The HYRes allows processing with a key feature: it uses virtually the same evaluation algorithm as in the visual evaluation of limiting resolution by evaluators. In practice, it has been demonstrated experimentally that it ensures a higher correlation with the visual evaluation (See Annex 4).

The HYRes algorithm is detailed referring to the flow charts in Fig. 1 in Annex 2 through Fig. 3 in Annex 2.

2. Description of processing

The HYRes is designed to scan the data in a rectangular area containing the wedge pattern shown in Fig. 1 in Annex 1 to detect the number of lines as mentioned earlier, with the horizontal direction defined as the principal scanning direction, and to sweep the frequencies with the vertical direction defined as the subscanning direction to determine the spatial frequency of the resolution limit.

a) Fig. 1 in Annex 2 shows the main flow of resolution measurement by the HYRes.
b) Fig. 2 in Annex 2 shows the sub flow SR1 for detection of the wedge starting line WSL corresponding to the m05 in the main flow, and the formula for calculating the number of lines of resolution.
c) Fig. 3 in Annex 2 shows the subflow SR2 corresponding to m10 in the main flow.
   * In the explanation here, the horizontal coordinate i takes the plus (+) sign in the

direction to the right, and the vertical coordinate j takes the plus (+) sign in the downward direction. The number of vertical pixels on the whole image is expressed as PHt, and the numbers of horizontal and vertical pixels on the selected rectangular image are expressed as Lx+1 and Ly+1 respectively. In addition, it is assumed that the lighter the image data, the larger the numerical value.

3. Main flow

The explanation in this section refers to Fig. 1 in Annex 2. In processing steps m01 and m02, image data is read, and in step m03, the average value of the white area in the data (the top line in the example) is defined as the background white level BWL. In step m04, the deviation average of the three smallest values is obtained as the noise level from the same area. This average value is used in the subsequent steps for setting the threshold (deviation average means an average of "deviations" or "differences of individual data from the mean of the entire data"). In the next step m05, the wedge starting line WSL (top edge) is detected. This will be used for detection of the length of the wedge and in the starting line of resolution limit evaluation loop. In step m06, a few (2 – 3) lines are added to the WSL to shift the starting line of the resolution limit evaluation loop in order to prevent possible malfunction due to the effects of various image processings including vertical aperture.

In steps m07 and m08, the initial values for individual threshold levels used for resolution limit evaluation loop are specified (they are set again in the loop). In step m09, other general parameters are initialized (the above-mentioned deviation average of three smallest values is also known as black-side half amplitude, because it may be considered as if a half amplitude i.e., a half of the total amplitude, is measured as the difference between the average value and the black level for the black/white (BW) waves).

In m10 and subsequent steps, the resolution limit is evaluated. In the SR2 processing described later, the number of black lines BCT is obtained for each line. The acquisition of the number of black lines in SR2 corresponds to the visual counting of the number of lines. Step m11 is a branch to evaluate whether or not the obtained number of black lines is equal to the original number of wedges WCT. When the equivalency is identified, evaluation on the next line is made in the line updating loop m23 through m25→m10. When nonequivalence is identified, the black line evaluation threshold level ETH1 is decreased for re-evaluation in the threshold updating loop m28→m29→m10 starting from the m12 branch.

Finally, when the number of detected black lines BCT becomes different from the number of wedges WCT, the line just before the unmatched numbers is detected as the resolution limit line LML (m14). Then the line updating loop is repeated through m31 to m33 starting from the m16 branch until no black line is detected for detection of the end line of wedge (jumping the processing steps m13→m16). When absence of black line is determined in m16, the corresponding line is detected as the wedge end line WEL.

The number of resolution lines is determined based on the wedge starting line WSL, wedge end line WEL and resolution limit line obtained as described above. The number of resolution lines may be determined from individual equations defined for different wedge types WCT ("Calculating the number of resolution lines" in Fig. 2 in Annex 2). The two equations are discussed in Fig. 2 in Annex 2.

When the resolution limit line LML is found within 3 lines or less from the wedge end line WEL, "complete resolution" is displayed with a prompt for changing the magnification of the chart and then the processing is terminated (m22→m36). This case is intended to protect for any unstable measurement due to the effects of vertical aperture or so. On the contrary, when the wedge end line WEL is not larger than the resolution limit line LML (such as when any error from m23 or m31 has been processed), an error message "unavailable measurement" is displayed and the processing is terminated (m19→m35).

4. Subflow SR1 for detecting the wedge starting line WSL

The explanation in this section refers to Fig. 2 in Annex 2. Basically, individual lines (j) are arranged in sequence to detect a line (s104) in which the relevant amplitude (deviation average [black-side half amplitude] of 3 smallest values adopted in this example) is found larger than a specified value ETH0 and define the line as WSL (s105). The detection threshold value ETH0 is specified in s101 (in this example, the value 5 times the noise level NL measured in m04). The s102 constitutes a transfer to the next line (increment), and the branch s103 → s106 provides error processing in the event when the detection of starting line fails.

5. Subflow SR2 for detecting the black line (obtaining the number of black lines BCT)

The explanation in this section is based on Fig. 3 in Annex 2. This flow is very important, and the intent is described in advance before the explanation of a specific control.

Human visual perception of the number of white/black lines is based on a very sophisticated judgment ability even if the person is unaware of it. In practice, for example, in the region of higher frequencies of wedge, especially near the resolution limit, amplitude becomes very small, and any local amplitude of the change in luminance corresponding to black/white lines may be smaller than the undulation (change in luminance at lower frequencies) developed across the entire wedge due to the effects of camera frequency characteristics and/or shading. In this case, there is a possibility that the value of a black line (the minimum luminance) is larger than the value of other white lines (the maximum luminance). Human eyes could distinguish the black and white lines of the wedge in response to their local changes without being affected by the effects of undulation due to shading.

In another case, in the lower frequency range of the wedge (the region of larger amplitude), oscillating changes in luminance of considerably large amplitude (ringing) can occur near the black/white edges due to the effects of camera frequency characteristics (especially the edge contrast processing); it is not rare that a change in luminance is much larger than the amplitude (change in luminance) of the wedge image near the resolution limit. Even in such a case, however, as long as the ringing amplitude is sufficiently smaller compared to the luminance amplitude of the wedge image at the relevant low frequency, human eyes could ignore it. In addition, human eyes could ignore any additional noise (random noise, etc.) superimposed usually on the whole image, where it is sufficiently smaller than the amplitude (change in luminance) of the wedge image at the relevant frequency. In short, human eyes could ignore any change smaller than the change in luminance of the wedge image, and never mistake any level in change due to noise with the wedge pattern to achieve the correct perception of black and white lines.

The HYRes black line detection algorithm is able to achieve the above-mentioned advanced perception by simple processing.

The sub flow discussed in this section is composed of three main blocks, s201 - s218 for detection of black lines in the right end, s219 - s236 for detection of black lines in the left end, and s237 and subsequent steps for detection of black lines in the intermediate region. This means that multiple black lines constituting the wedge are detected and counted in the right end, left end, and the intermediate region in this order. Separating the both ends is intended to eliminate the above-mentioned ringing effects. First, description is made about detection of intermediate black lines.

As a rule, any change in luminance data in one line is checked to detect a black line as minimum value. In practice, however, in order to ignore any relatively smaller change due to noise as described above, proper processing is necessary to accept only a change that exceeds a predefined limit value. Then, in actuality, such increase or decrease has been defined as effective for detection that involves a decrease below ETH1 from the local maximum value LMx (s238) or an increase above ETH1 from the local minimum value LMn (s239). The local maximum value LMx and the local minimum value LMn mean "the maximum and minimum values for the data remaining active to date since the last detection of any effective change", because a reset to that data occurs when the above-mentioned effective change (exceeding the threshold ETH1) is detected (s246, s247), although unless an effective change is detected, LMn is updated to that data when the data value is smaller than LMn (s248), or LMx is updated to that data when the data value is larger than LMx (s249). By detecting only such decrease or increase exceeding the specified thresholds for local maximum value or local minimum value in this way, the effect of noise and undulation may be eliminated so as to correctly detect black and white lines as extreme values (and thus the threshold ETH1 corresponds to the sensitivity for detection of change).

Detection of black line (identification of minimum value) is implemented in s243 by identification of any decrease (flag setting z(i)=0 through s238 → s246) followed by identification of any increase (flag setting z(i)=1 through s239 → s247). Unless the minimum value is detected, evaluation is repeated for the next column through the loop s244 and 245 → s238.

Once the minimum value is detected, relevant column position i-1 is registered as a black line position for the corresponding line j (s250: not mandatory for convenient utilization of information) and the number of black lines BCT in s251 is increased by one.

The value of the threshold ETH1 used for evaluation of black line detection is decreased as required as described above in the threshold updating loop m27 - m28 → m10 in the main flow. In actuality, the threshold ETH1 is defined relatively larger during the detection of black/white detection in the lower frequency range at the initial stage of measurement processing, and the threshold ETH1 is decreased for repeated detection only when detection of the specified number of lines fails with the ongoing threshold, as detection proceeds to a higher frequency range.

Detection in both ends, right and left, is implemented in a similar manner before the detection of the intermediate black line, with the major differences as listed below.

- As the detection proceeds from the outside to the inside of the wedge, in right-end detection, the scanning direction is reversed between right and left (s210). The right-end position is registered as the boundary end BEnd for forward scanning (s218).
- In order to avoid the effects of ringing, only the decrease identification uses a threshold ETH2 different from ETH1 (s204, s221). The value for ETH2 is determined in either step m25 or m32 in the main flow based on the amplitude of the relevant line (1/4 of the black-side half value).
- The scanning start position is re-selected for individual lines (j) (s213, s230). This processing is intended to avoid the scale (graduated) images provided with the wedge for visual reading. This step is branched at s204 (s221) in which detection is completed in the right (left) end of wedge and thus, based on the i (value detected in the end) at that point of time, the position is specified so that it is shifted toward the outside of the wedge by a few pixels, with some margin included to keep away from the scale area.

In this way, detection of black lines is implemented starting at the right end (s201 - s218) then at the left end (s219 - s236) and the intermediate region (s237 and subsequent steps). When, in the process of detecting black lines in the intermediate region, the scanning region in s245 reaches the scanning boundary end BEnd, detection of black lines in the relevant line is completed (s245 - s253).

6. Summary

In conclusion, the HYRes resolution limit evaluation algorithm offers the features listed below and allows a software-based evaluation comparable to visual measurement, which has not been achieved conventionally.

- Detection of black lines is based only on the change in data (extreme value) as a rule, allowing detection of waves (black lines) irrespective of any undulation due to shading and other causes.
- Detection can target the change in luminance with the smallest response since the effects of noise may be appropriately eliminated corresponding to respective frequency ranges and detection is implemented in the end at ETH1 = 0 (at the resolution limit frequency). This suggests that the wedge pattern can be detected over the entire frequency range and to the possible limit.

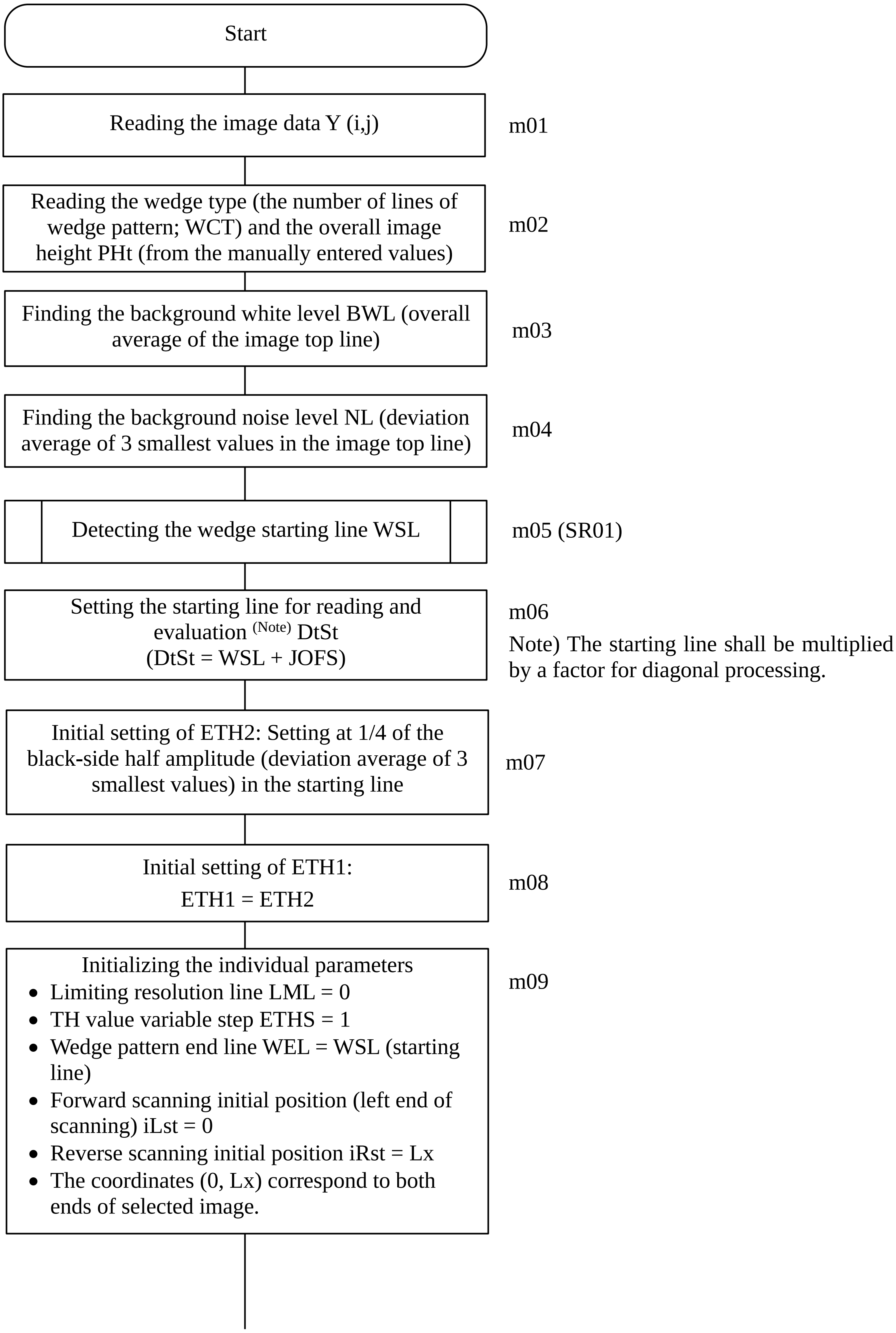


Fig.1a in Annex 2　HYRes main flow (To be continued to Fig.1b)

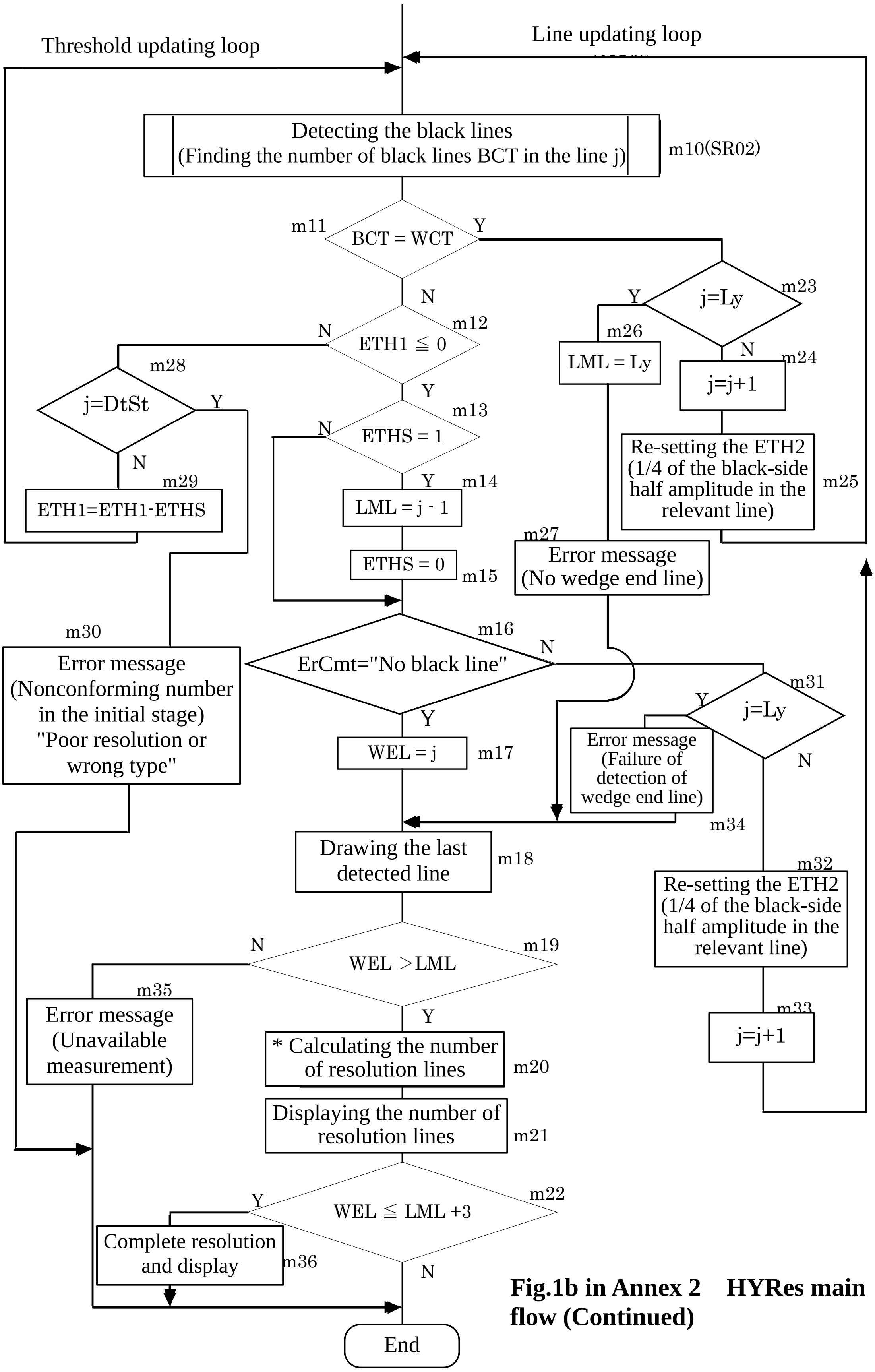


Fig.1b in Annex 2 HYRes main flow (Continued)

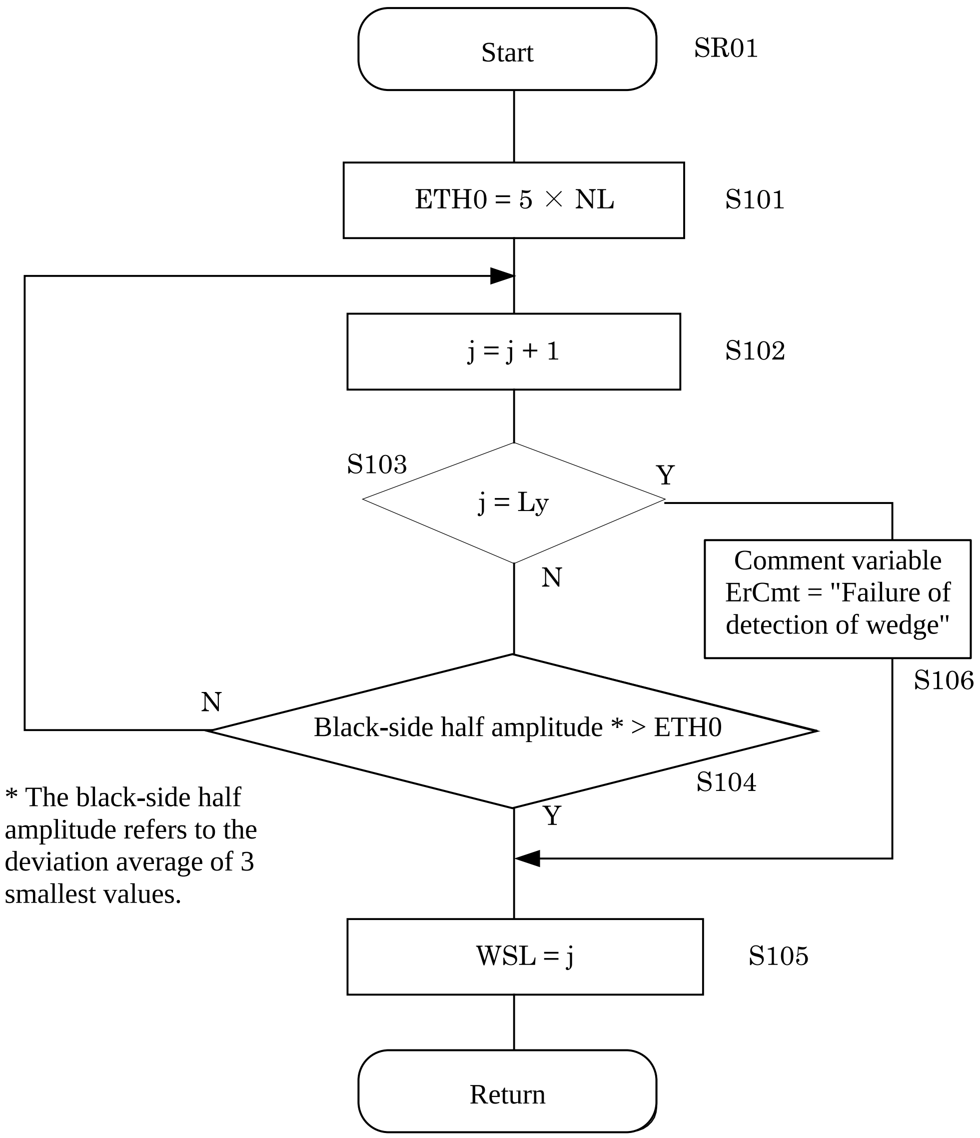


Fig.2 in Annex 2
Sub flow for detection of wedge starting line WSL and the formulas for calculating the number of resolution lines

Formulas for calculating the number of resolution lines (See the note of 3 in annex 1)

WCT = 5 (In the case of a 5-line wedge)

$$Res = \frac{100 + 500 \times (LML - WSL)/(WEL - WSL)}{10/3 \times (WEL - WSL)/PHt}$$

WCT = 9 (In the case of a 9-line wedge)

$$Res = \frac{500 + 1500 \times (LML - WSL)/(WEL - WSL)}{10/3 \times (WEL - WSL)/PHt}$$

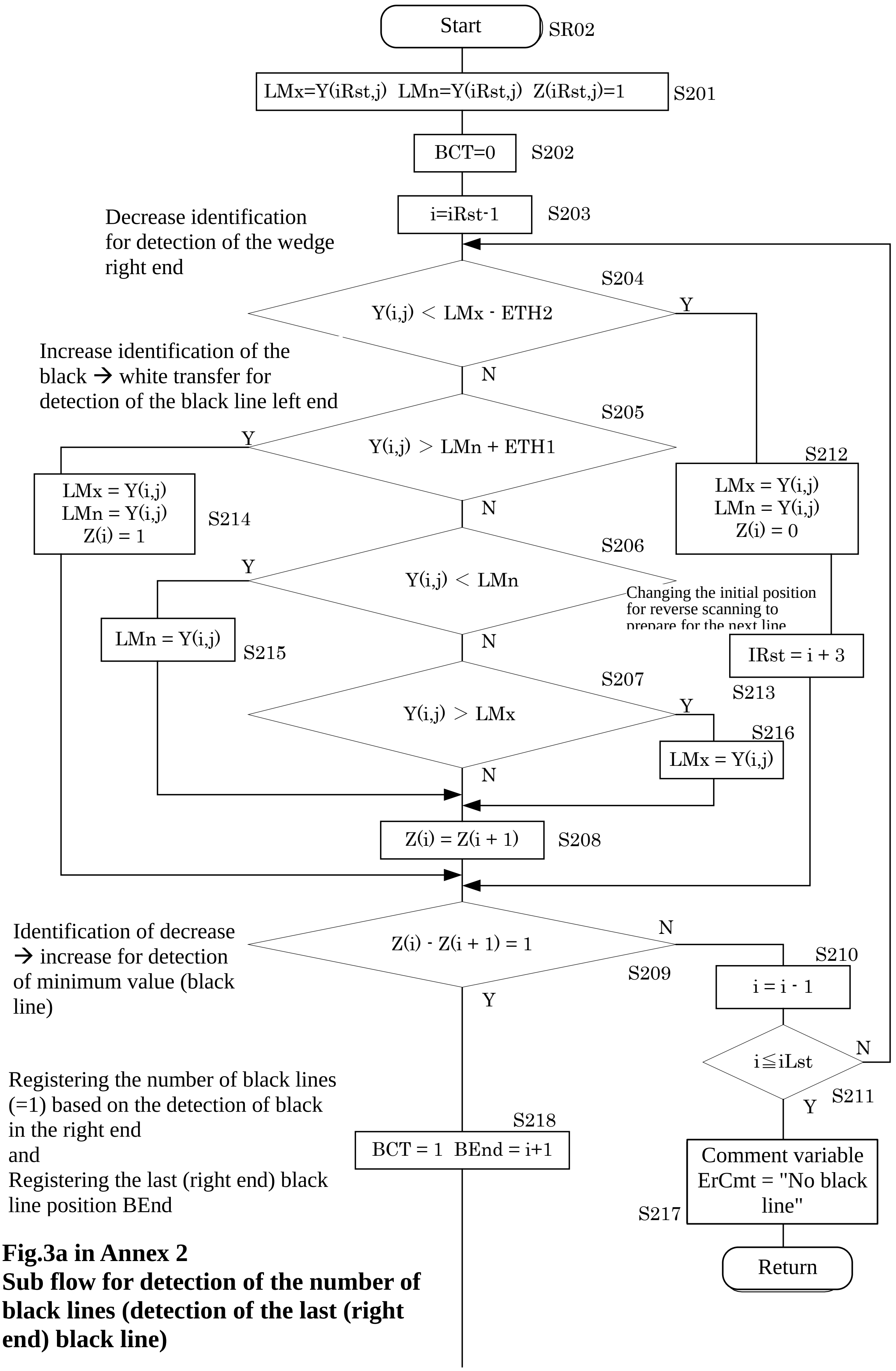


Fig.3a in Annex 2
Sub flow for detection of the number of black lines (detection of the last (right end) black line)

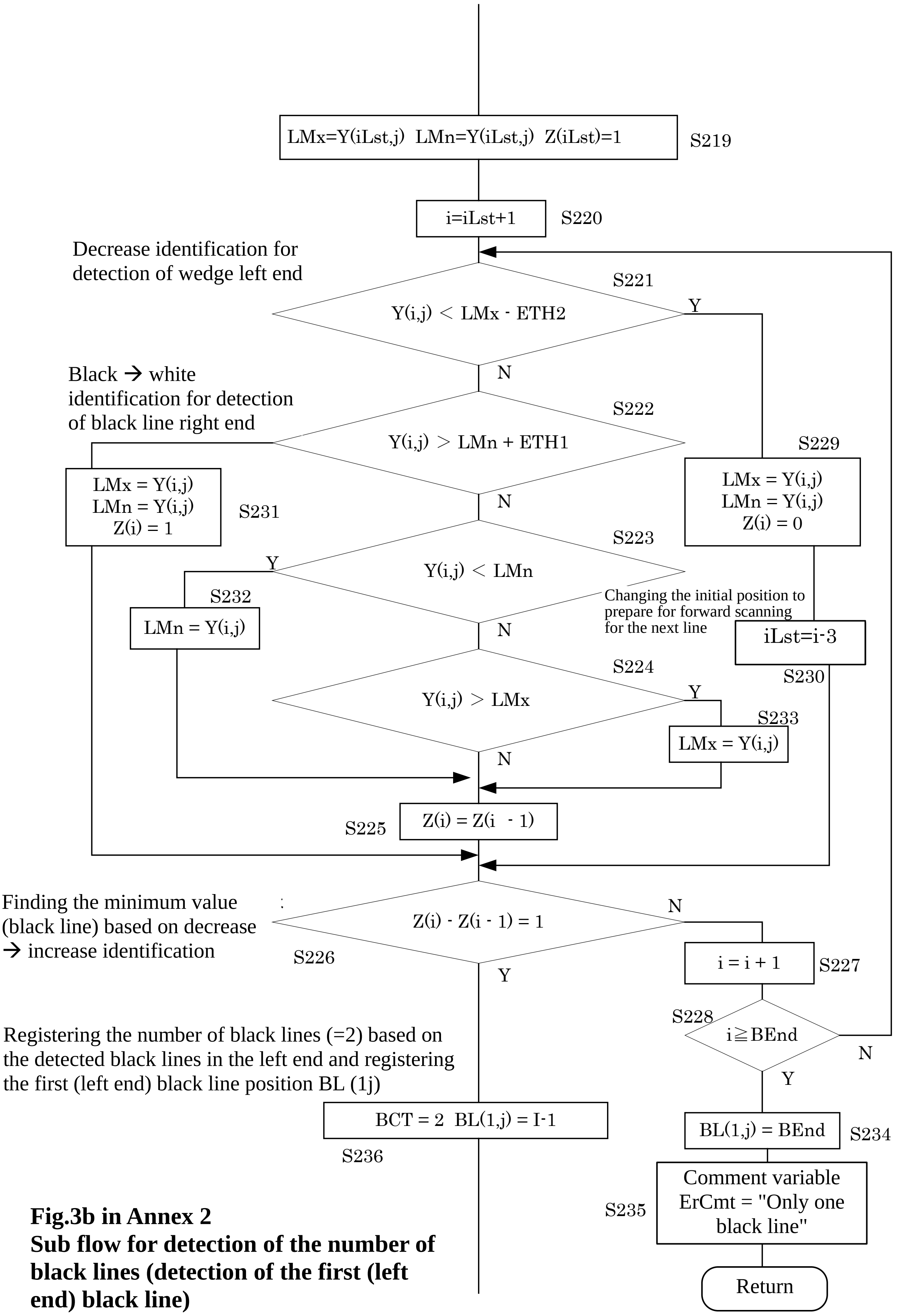


Fig.3b in Annex 2
Sub flow for detection of the number of black lines (detection of the first (left end) black line)

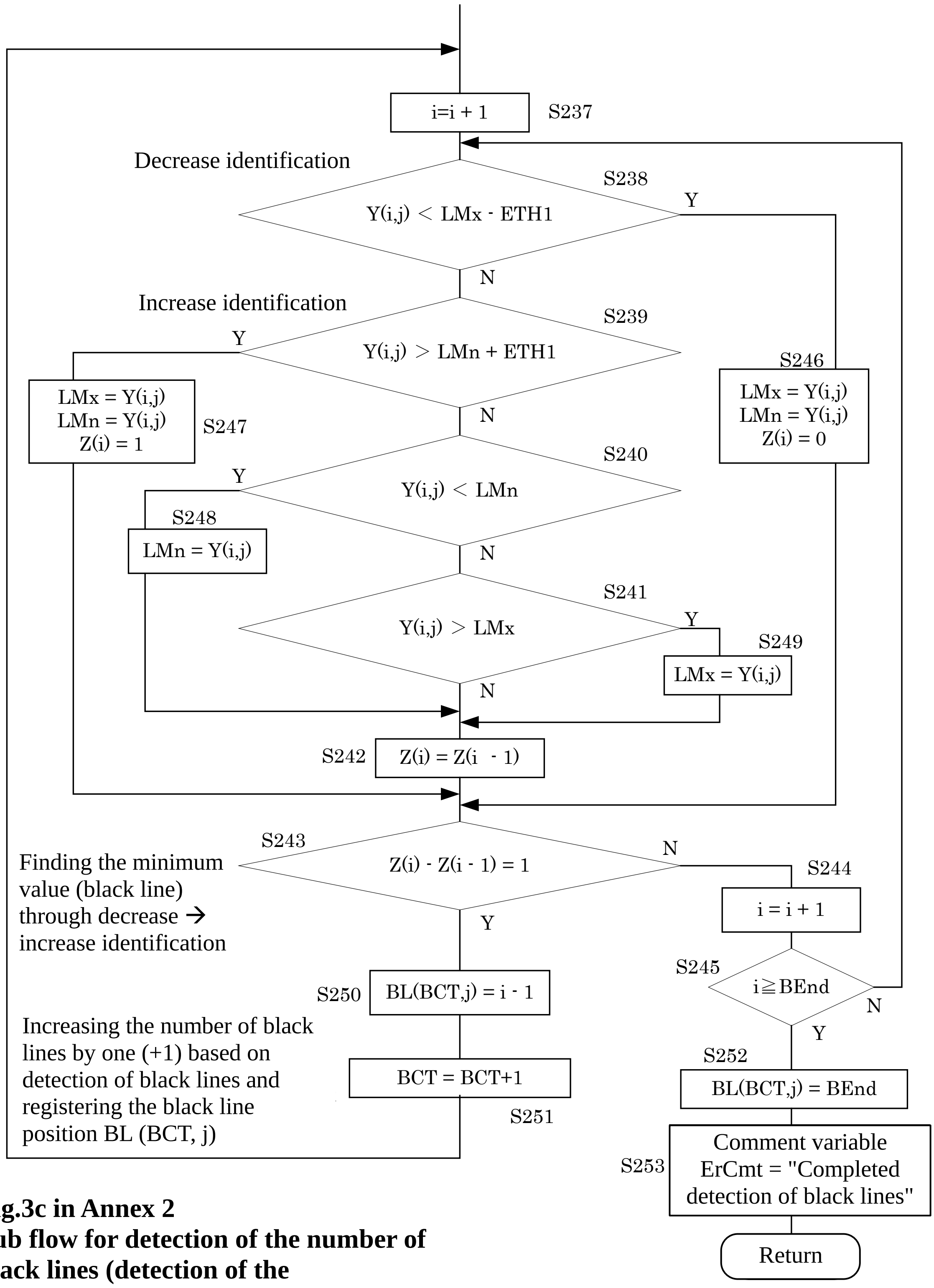


Fig.3c in Annex 2
Sub flow for detection of the number of black lines (detection of the intermediate black lines)

Annex 3 (Informative) The HYRot 45-Degree Image Rotation Algorithm for Resolution Measurement

1. Background

The HYRes software, which performs processing equivalent to visual resolution measurement, was discussed in Annex 1 and Annex 2. HYRes is designed to scan in the horizontal direction, so for testing resolution with the same software in the vertical and 45-degree diagonal directions, the image must be rotated before scanning. The method of 90-degree rotation is not specified, since normally this does not affect image quality (unless some special processing is performed). In the case of 45-degree rotation, however, some kind of interpolation (including pre-interpolation) is necessary. Since the interpolation method is likely to affect resolution, a standard method must be decided.

The following description presupposes pre-interpolation.

2. Processing

Consideration was made for the following two points. (1) Pixel sampling during 45-degree rotation results in data loss, so sampling is not performed. (2) When pixels are augmented, averaging of the adjacent values on both sides produces gray if done between white and black. Producing a color that was not present originally could have undesirable effects; therefore pre-interpolation is used.

The algorithm for 45-degree rotation in accord with the above two considerations was incorporated in the HYRes. Fig. 1 and Fig. 2 in Annex 3 show typical data before and after processing. In this example rotation is clockwise, but counter-clockwise rotation is of course possible as well.

5	10	15	20	25
4	9	14	19	24
3	8	13	18	23
2	7	12	17	22
1	6	11	16	21

Fig. 1 in Annex 3 Array prior to 45-degree rotation

				5				
			4	5	10			
		3	4	9	10	15		
	2	3	8	9	14	15	20	
1	2	7	8	13	14	19	20	25
1	6	7	12	13	18	19	24	25
	6	11	12	17	18	23	24	
		11	16	17	22	23		
			16	21	22			
				21				

Fig. 2 in Annex 3 Example of 45-degree clockwise rotation of Fig. 1 in Annex 3

When an image with a horizontal pixel count Lx and vertical pixel count Ly is rotated clockwise 45 degrees, two sets of data are produced from the original image data X(i, j) using Equations (3-1) and (3-2).

$$Y(Ly + i - j, i + j) = X(i, j) \qquad (3\text{-}1)$$

$$Y(Ly + i - j, i + j + 1) = X(i, j) \qquad (3\text{-}2)$$

For 45-degree rotation counter-clockwise, two sets of data are produced from the original image data X(i, j) using Equations (3-3) and (3-4).

$$Y(i + j, Lx - i + j) = X(i, j) \qquad (3\text{-}3)$$

$$Y(i + j, Lx - i + j + 1) = X(i, j) \qquad (3\text{-}4)$$

Annex 4 (Informative) Findings from Experiments for the Establishment of This Standard

Note that "lines" is sometimes used as an abbreviating expression of "LW/PH" in this annex.

During the course of establishing this standard, five interested members performed several experiments. The members involved are listed in the Explanation.

1. Variation in visual resolution measurement (on a printout and monitor)

Visual resolution evaluation methods without any measuring instrument are relatively simple, although they have the disadvantage of causing different results depending on the different evaluators involved, and/or of failing to assure consistent reproducibility. Tests were conducted in order to identify possible variations in the results obtained,.

The requirement regarding the notation of resolution in units of 50 lines has been adopted in this standard based on the results of those experiments.

1.1 Variations in visual evaluation on a printout

The ISO chart was shot by a total of 18 DSCs, printed by the Fuji Photo Film Co., Ltd. Model PG4000 printer in the A3 size, and evaluated by the interested members for visual resolution measurements. The results are summarized in Table 1 in Annex 4.

	Average	SD
Horizontal	57.9	37.5
Vertical	78.5	36.1
45-degree diagonal	75.7	55.1

Table 1 in Annex 4 Variation in the lines of visual resolution on a printout (Variation=Max. value-Min. value)

1.2 Variations in visual evaluation on a monitor

Subsequent to the evaluation of visual resolution measurements on a printout, the same image data was viewed by the members on their own monitors to determine the visual resolution measurements. The magnifying power and other setting conditions were left at the discretion of the individual members. In actuality, one member used an LCD monitor, and the other four used their own CRT monitors for evaluation, but no significant difference was observed. The results are summarized in Table 2 in Annex 4.

The variation or standard deviation (SD) is smaller than that obtained in the evaluation on a printout, although this may be attributed to the fact that the members have become skilled in the evaluation procedure. (Involvement of a single evaluator may minimize variations as he/she becomes skilled in the evaluation by repeating the procedure.)

	Average	SD
Horizontal	59.9	28.1
Vertical	72.1	37.3
45-degree diagonal	68.7	43.5

Table 2 in Annex 4 Variation in the lines of visual resolution on a monitor (Variation=Max. value-Min. value)

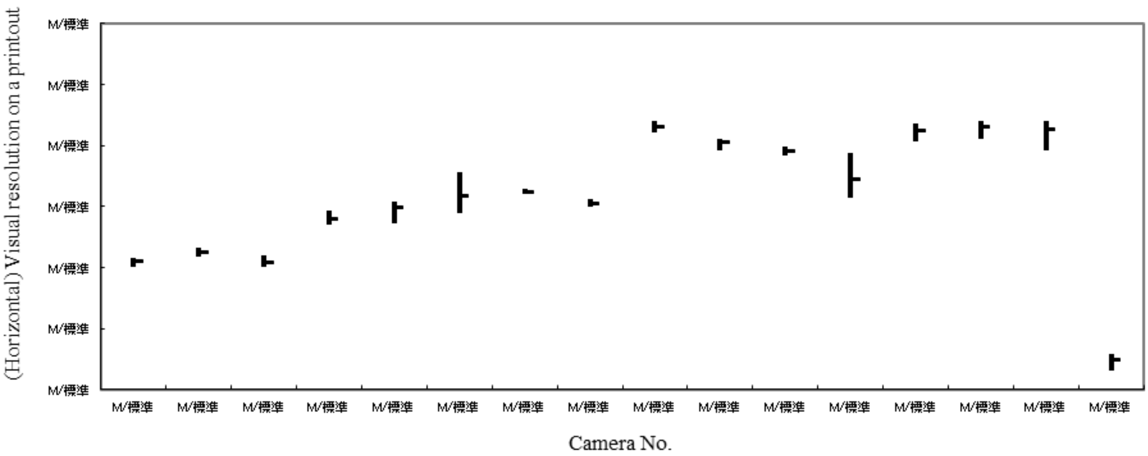
2. Difference between computer software-based and visual resolution measurements

Comparison was made between the calculated results from the computer software HYRes2 and the visual resolution measurements on a monitor (average value by the five members) with the results summarized in Table 3 in Annex 4. Fairly good agreement was observed, and it was decided to adopt the software-based visual resolution measurements.

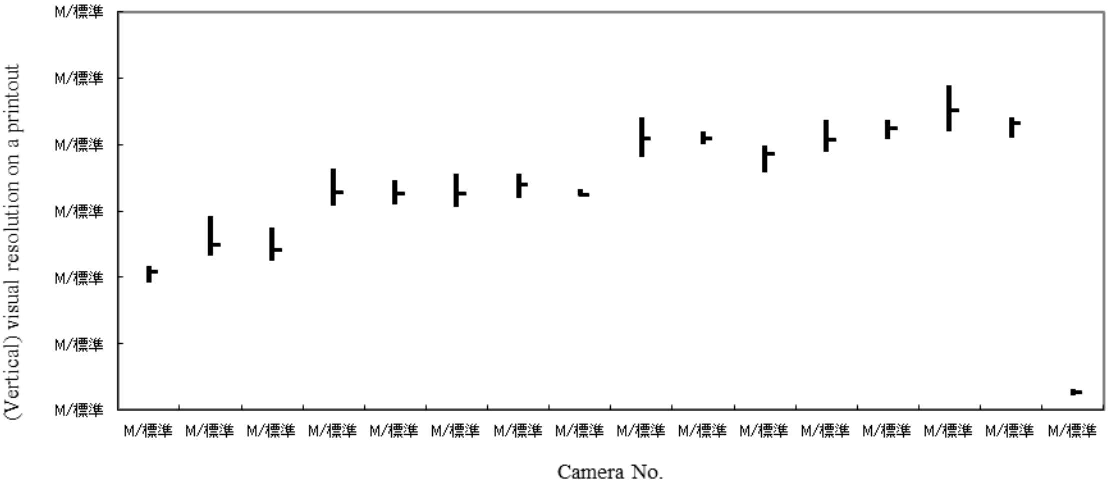
	Average	SD
Horizontal	26.1	16.1
Vertical	19.8	22.8
45-degree diagonal	29.5	19.2

Table 3 in Annex 4 Difference between the visual resolution measurements on a monitor and the software calculated values

a) Range of variations of (horizontal) lines of visual resolution on a printout



b) Range of variations of (vertical) lines of visual resolution on a printout



c) Range of variations of (diagonal) lines of visual resolution on a printout

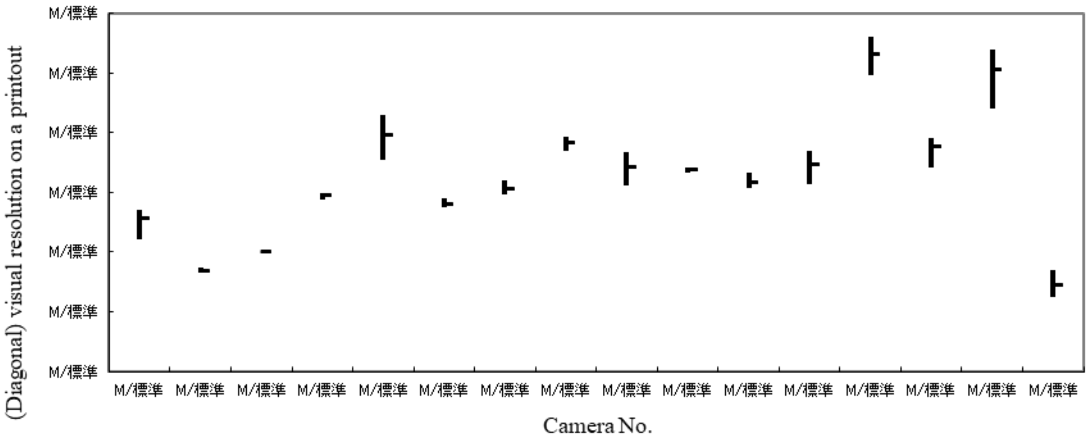


Fig.1 in Annex 4 Variation in the lines of visual resolution on a printout

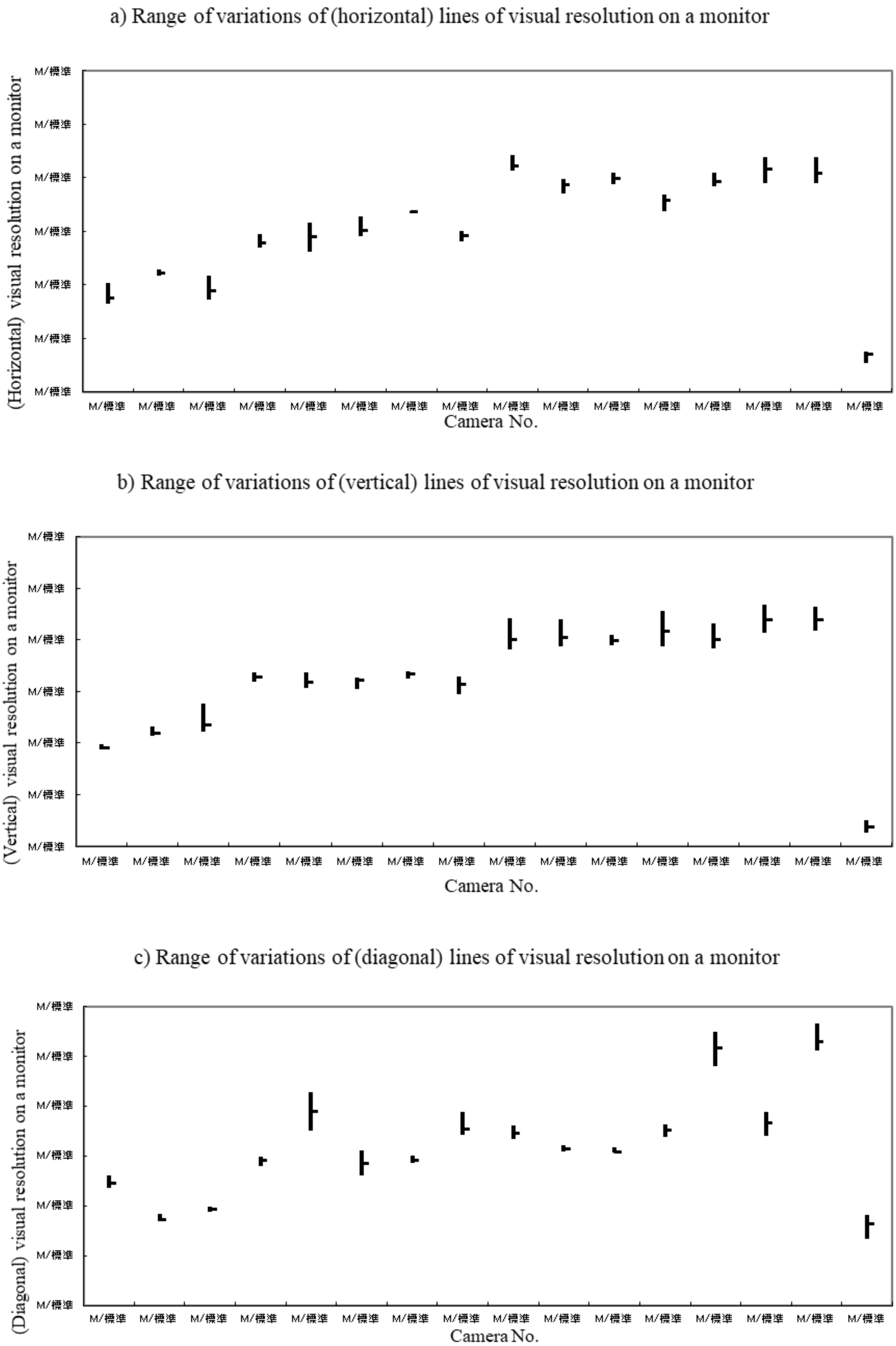
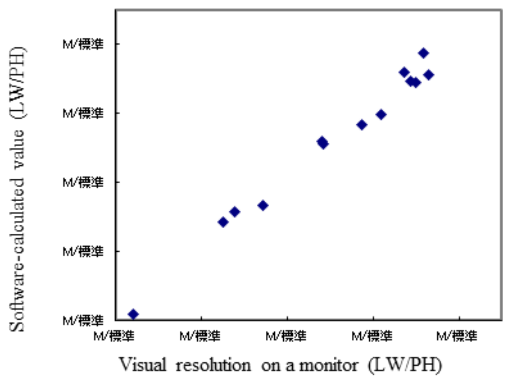
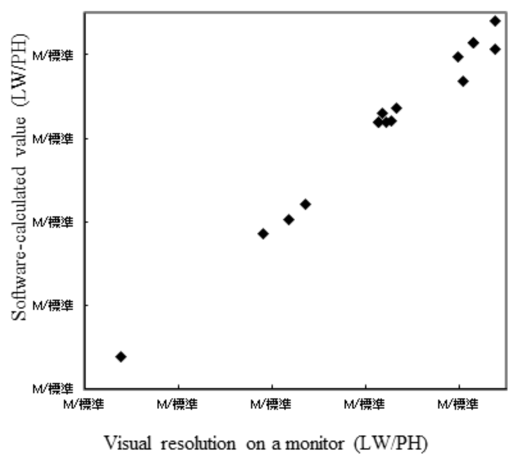


Fig.2 in Annex 4　Variation in the lines of visual resolution on a monitor

a) Visual-evaluated and software-calculated values (Horizontal)



b) Visual-evaluated and software-calculated values (Vertical)



c) Visual-evaluated and software-calculated values (diagonal)

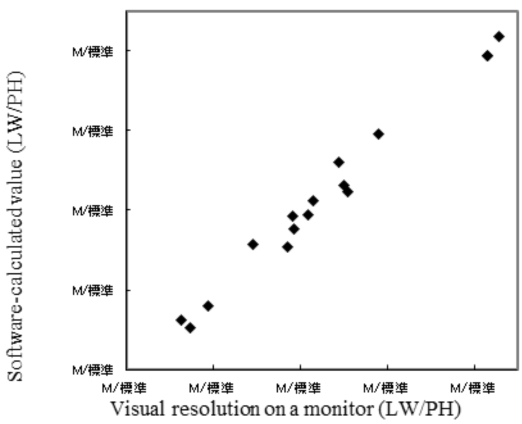


Fig.3 in Annex 4 Visual resolution on a monitor and software-calculated resolution

Digital Still Camera Resolution Measurement Method --- Explanation

This informative section describes the items stipulated and included in this standard and Annex and those in connection with the items, and thus it does not constitute a part of this standard.

Note that the "chief" in Explanation 1 is the sub working group chief at the time of the first edition issue.

1. Purpose and Progress of Standard

1.1 Purpose

In the spring in 2000, Fuji Photo Film Co., Ltd. proposed to the Japan Camera Industry Association (JCIA, the designation at that time: the present CIPA) to standardize the notation of resolution with the intention of including resolution data in the DSC catalogs. JCIA responded to this proposal by sending out questionnaires to the member companies in May 16, 2000. A total of 14 companies filled out the questionnaires and they were all in favor of taking the proposal under deliberation, and 12 of them declared their participation in the deliberation. Then under the JCIA Digital Camera Technical Working Group, the Resolution Sub-Working Group was formed. The Sub-Working Group was supervised by the propose Fuji Photo Film Co., Ltd. The first meeting was held on August 28.

1.2 Progress of deliberation

At the start of the Sub-Working Group, ISO12233, the standard for resolution measurement methods for DSC, was formally established. Then the supervisor proposed a plan to make reference to ISO12233 to the utmost for all the items including the test charts and the tools required for resolution measurement, and all the members agreed with the plan.

At the beginning, the supervisor proposed to use the limiting resolution specified in ISO12233:2000 and made the software available. Against this, a few members proposed the visual resolution measurement. In addition, a few members had some doubts about the standard itself, asking if it would be reliable enough to determine resolution because DSC could cause aliasing. Then, in order to discuss technical problems, a working group was formed including 6 representative members.

The working group conducted experiments and found that the limiting resolution could show unusually larger values due to the effects of aliasing in some cases. On the other hand, visual resolution measurement was found to suppress possible outlying observation by specifying two rules: a) to determine the resolution in the form of the spatial frequency at which the number of wedge lines on the visual resolution evaluation pattern changed (e.g., 5 line → 4 lines); and b) to start observation always in the lower frequency range. Images of test charts were evaluated on both hard-copy printouts and on monitors with fairly good agreement observed between both media, as well as similar variations. A member additionally proposed to integrate the two rules into the software program as well as to develop the software, and the working group also tested the software. The test showed good agreement between the software-based calculated values and visual measurements (See Annex 4).

Based on the above-mentioned results, the working group proposed to the Sub-Working Group a) to adopt the visual resolution measurement as the standard resolution measurement method, and b) to allow using either media, hard-copy printout, monitor, or software, for evaluation of resolution.

The Sub-Working Group discussed the proposal. The most controversial topic was how the results should be noted. (See **2. Topics in question during the course of the discussion**.) After active discussion, the conclusion reached at the 20th meeting of the Sub-Working Group held in July 26, 2002 was approved as the final draft, and at the 21st meeting of Sub-Working Group in September 11, 2002, technical discussion was completed without any objection.

2. Topics in question during the course of the discussion

The most actively discussed topic throughout the meetings of the Sub-Working Group was how the results should be noted.

Unlike films which provide the same resolution results in any direction, DSC resolution differs between horizontal and vertical directions. Also, in the 45-degree diagonal direction, it is estimated differently between the diagonal to the upper right and diagonal to the lower left. Then it has been a hard problem to deal with to which extent the results should be noted. After a heated discussion, the matter was settled as specified in this standard (**7. Notation of Resolution**), though considerable efforts were necessary to iron out the differences of opinion and reach agreement.

Deliberation Committee The deliberations for the drafting of this Standard were conducted mainly by a sub-working group under the Technical Working Group of the Standardization Committee, namely the Resolution Sub-Working Group.

Standardization Committee

Chair	Suzuki Masao	Canon Inc.
Vice Chair	Satoh Hitoshi	FUJIFILM Corporation
Vice Chair	Imafuji Kazuharu	NIKON CORPORATION
Vice Chair	Yoshida Hideaki	Olympus Corporation
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Vice Chair	Katoh Naoya	Sony Imaging Products & Solutions Inc.

Technical Working Group

Leader	Udagawa Yoshiro	Canon Inc.
Sub Leader	Houshuyama Hideo	NIKON CORPORATION
Sub Leader	Yoshida Hideaki	Olympus Corporation

Resolution Sub-Working Group

Chief	Yoshida Hideaki	Olympus Corporation
	Paul Hubel	Apple, Inc.
	Mori Munehiro	Apple, Inc.
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	Takagi Atsushi	Canon Inc.
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