Standard of the Camera & Imaging Products Association

CIPA DC-003-Translation-2003

Resolution Measurement Methods for Digital Cameras

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

Established in December 17, 2003

Prepared by

Standardization Committee

Published by

Camera & Imaging Products Association

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Resolution Measurement Methods for Digital Cameras

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 and Documents

The following normative documents contain provisions which, through reference in this text, constitute provisions of this standard. These documents shall be applied according to the latest issue in force (including amendments).

ISO12233: 2000 Photography - Electronic still-picture cameras - Resolution measurements

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

3. Terms and Definitions

a) **Resolution** is the ability of a camera to resolve detailed patterns while excluding the effects of aliasing. It is expressed as the number of lines per picture height.

b) **Aliasing** refers to the noise produced when sideband waves around the higher harmonics of sampling frequency are superimposed when the sampling frequency is smaller than twice the maximum frequency of the image signal (New Edition Glossary for Photography issued by Shashin Kogyo Shuppan Co., Ltd. in 1988).

4. Test Charts

4.1 ISO12233 resolution test chart

This standard is based on the ISO12233 and it adopts the ISO12233 resolution test chart (**Fig. 4.1**, hereinafter "ISO chart"). The ISO chart contains a variety of patterns, but for the visual resolution measurements in this standard, use is made of horizontal patterns J1 and K1, vertical patterns J2 and K2, and 45-degree diagonal patterns JD and KD. (ISO12233 specifies three types of measurement methods which are described in **9. Notes on ISO12233** in conjunction with the ordering information for the ISO chart.)

The ISO chart does not have to be used in its entirety; the relevant patterns may be extracted and rearranged.

4.2 Meaning of numbers on the ISO chart

The ISO chart is designed so that when the height of the active target (the vertical distance inside the black border of **Fig. 4.1** viewed lengthwise) fills the vertical picture height, the number of lines per picture height 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 ISO chart

A chart similar to the ISO chart may be created and used. In that case it shall meet the following requirements stipulated in ISO12233. (The ISO chart of course already meets these requirements.)

a) The ratio of the maximum chart reflectance Rmax and the minimum chart reflectance Rmin for large test pattern areas shall be not less than 40:1 and not greater than 80:1 (80Rmax/40Rmin) (ISO12233 4.5).

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 test chart height. (ISO12233 4.8)

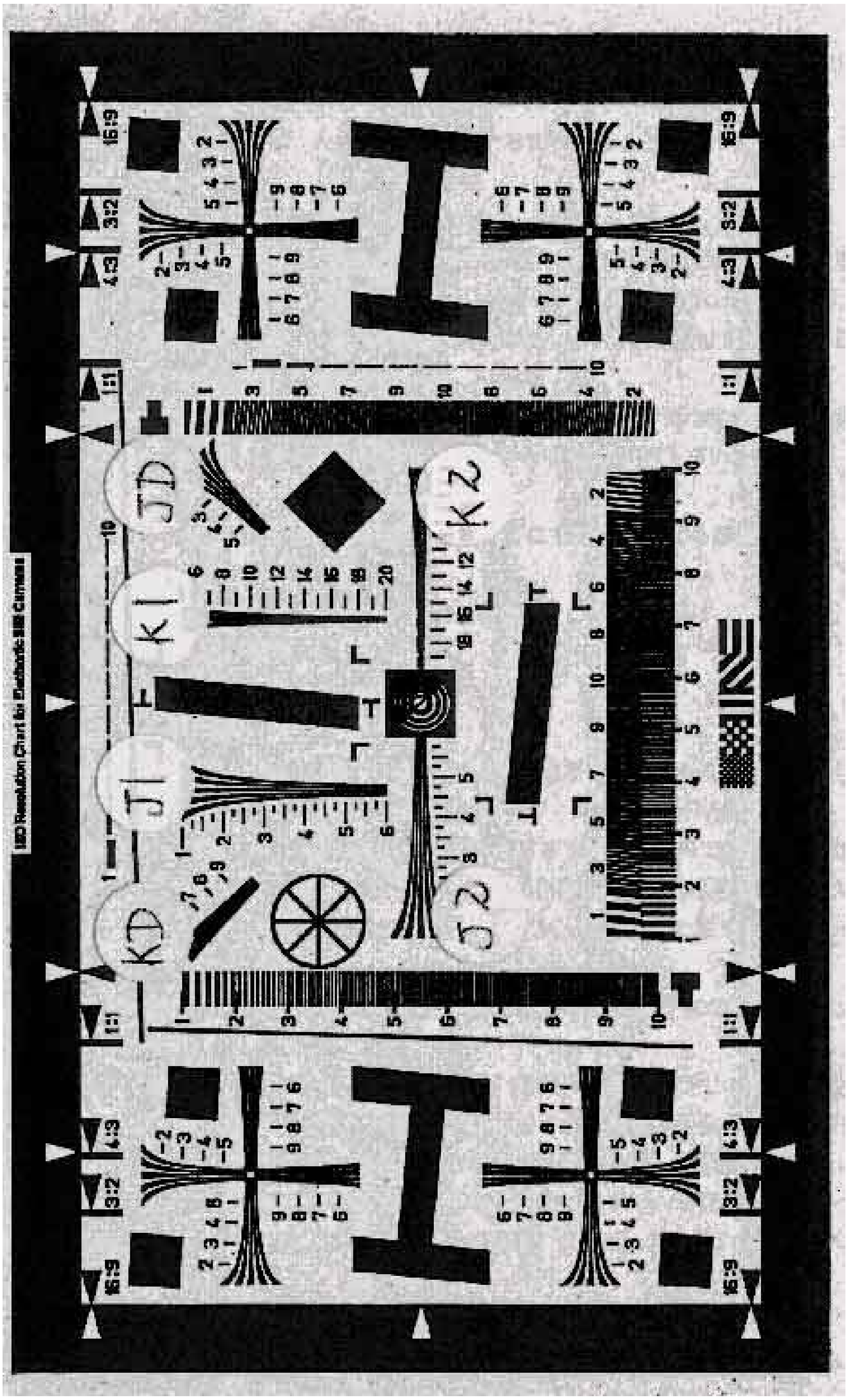
c) The line width tolerance shall be within ±5% (ISO12233 4.8).

d) The modulation ratio Rmax/Rmin for the finest features of hyperbolic wedges K1 and K2 should be 18 or above. The level of this requirement is "recommended." (ISO12233 Annex B)

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.

Fig.4.1 ISO12233 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 when viewed lengthwise) should fill the picture fully. In practice this is difficult to accomplish, and it is allowable to fall somewhat short of filling the picture fully. In such cases it is necessary to calibrate the results, dividing the number of image lines in the camera image by the number of lines in the active chart area, and multiplying this fraction by the test chart values.

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 may be considered by individual makers 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.

5.5 Focusing

Not specified.

5.6 White balance

The camera should 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 it either on a monitor or as a hard-copy printout. Evaluation using software that performs the equivalent processing as visual evaluation is also possible.

6.1 Evaluation using a hard-copy printout

Evaluations shall be made as follows to ensure consistency.

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.

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

A printout of any desired magnification may be used.

6.2 Evaluation on a monitor

Evaluations shall be made as follows to ensure consistency.

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.

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

Any desired magnification may be used for viewing on a monitor.

6.3 Measurement by software

Visual resolution evaluation can be made by either of the methods described in **6.1** and **6.2** above. 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 display 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. 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 was tested by individual members (10 in total) with the results in good agreement with the visual measurements, and then it was included in this standard. The software 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.

Internet users can visit the web site providing the electronic version file of this standard to download the software discussed in Annex 1, Annex 2 and Annex 3. 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. Any resolution exceeding 600 lines is preferably noted in units of 50 lines. The reason for this rule to report the resolution in units of 50 lines is described in Annex 4.

The CIPA Standard for Resolution Measurement Methods specifies 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 (the simple "45-degree diagonal" can cause different values in the different directions, diagonal to the upper right and diagonal to the lower right). Notation of resolution shall always include the smallest value among the measurements obtained in the four directions.

When reporting any value(s) other than the smallest one, it shall be always accompanied by the smallest value.

7.2 Resolution measuring direction

When reporting the resolution values obtained in two or more measuring directions, the relevant resolution measuring directions shall be noted. 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." In addition, when reporting the value in either direction of "45-degree diagonal to the upper right" or "45-degree diagonal to the lower right," the direction may be expressed simply as "diagonal."

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.

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**.)

8. Examples of Notations

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

Example 1) Notation of only the smallest value

Resolution: 1100 lines (in accordance with CIPA)

Example 2) Notation of the largest and smallest values

Resolution: Horizontal 1250 lines, diagonal 1100 lines (based on the CIPA Standard)

Example 3) Notation of horizontal resolution, vertical resolution and the smallest value

Resolution: Horizontal 1250 lines, vertical 1200 lines, diagonal 1100 lines (CIPA)

Example 4) Notation of all values

Resolution: Horizontal 1250 lines, vertical 1200 lines, diagonal to the upper right 1150 lines, diagonal to the lower right 1100 lines (based on the CIPA Standard; Evaluated on a monitor)

Example 5) Notation of added camera settings

Resolution: 1100 lines (in the case of RAW recording, in other cases based on the CIPA Standard; Evaluated on a monitor)

9. Notes on ISO12233

The ISO12233 standard for DSC resolution measurement methods was established in 2000. This CIPA standard specifies as the standard resolution measurement method the visual resolution measurement, one of the three methods recommended in the ISO12233.

ISO12233 in addition to visual resolution covers limiting resolution and spatial frequency response (SFR). Experiments made in conjunction with this specification project showed that the limiting resolution method can result in extremely high values due to the influence of aliasing. SFR makes use of Fourier analysis on the region between black and white edges. It had the disadvantages of large variability, sometimes producing results widely at variance from those obtained by visual resolution or limiting resolution methods. (See, e.g., Sachio Okano, Japanese Journal of Optics, 5(6), p.582 (1998).)

A copy of the ISO chart can be obtained from O.T.O Research Corporation (Takeuchi Building, 1-34-12 Takadanobaba, Shinjuku-ku, Tokyo 169-0075; Tel. +81-3-3208-7821, Fax +81-3-3200-2889). Technical inquiries are handled in Japan by the ISO/TC42 local chapter (JCII Building, 25, Ichiban-cho, Chiyoda-ku, Tokyo 102-0082; Tel. +81-3-5276-3561, Fax +81-3-5276-3563). When ordering, please specify the "ISO12233 standard electronic still camera resolution chart."

Annex 1 (Informative) The HYRes Software for Evaluation of Limiting Resolution

As mentioned in the text, use of computer software for visual resolution measurements was proposed by one of the members during the course of development of this standard. The supplied software was tested at individual member companies and it was found capable of providing results in good agreement with the visual resolution measurements, and then it was included in this standard. Annex 1 provides a brief description of the software (the algorithm is detailed in Annex 2). In this standard, the software is called HYRes.

1. Preprocessing: Selecting the region of interest

The HYRes supports the BMP file format. Any image data recorded by any format other than this format 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 pattern of interest for evaluation of visual resolution is extracted. 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 plane intersects the wedge, the HYRes automatically identifies the data and rotates it for calculation. Since 45-degree rotation could affect resolution measurement depending on the method used, consideration was given to observing the two following requirements:

a) To eliminate cropping 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.

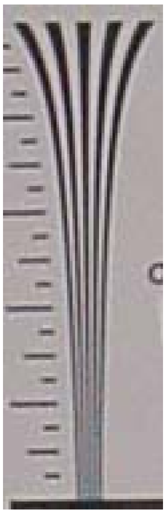


Fig. 1 in Annex 1

2. Main processing and 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.

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 limiting resolution 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 resolution

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 picture height (20cm), or 6 cm. Although the ISO chart was designed so 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:

$$\text{Resolution} = (100 + 500 \times (\text{LML} - \text{WSL}) / (\text{WEL} - \text{WSL})) \times C \quad \cdot\cdot \quad (1\text{-}1),$$

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

$$\text{Resolution} = (500 + 1500 \times (\text{LML} - \text{WSL}) / (\text{WEL} - \text{WSL})) \times C \quad \cdots \quad (1\text{-}2)$$

Here compensation factor C is calculated as follows:

$$C = 0.3 \times \text{PHT} / (\text{WEL} - \text{WSL}) \quad \cdots \quad (1\text{-}3)$$

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

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 limiting resolution. 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 individual frequency ranges and detection is implemented in the end at ETH1 = 0 (at the limiting resolution frequency). This suggests that the wedge pattern can be detected over the entire frequency range and to the possible limit.

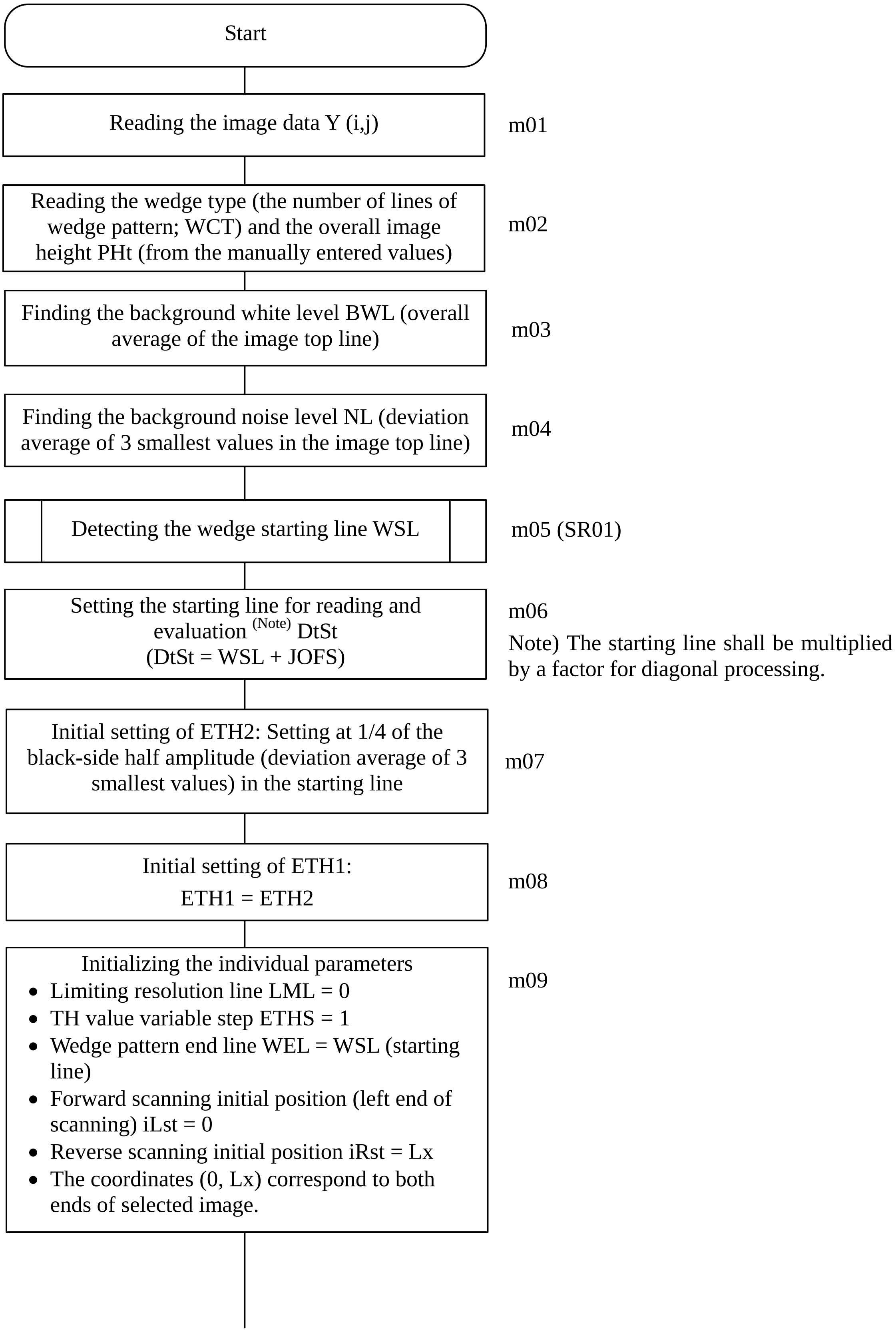


Fig.1a in Annex 2 HYRes main flow (To be continued to Fig.1b)

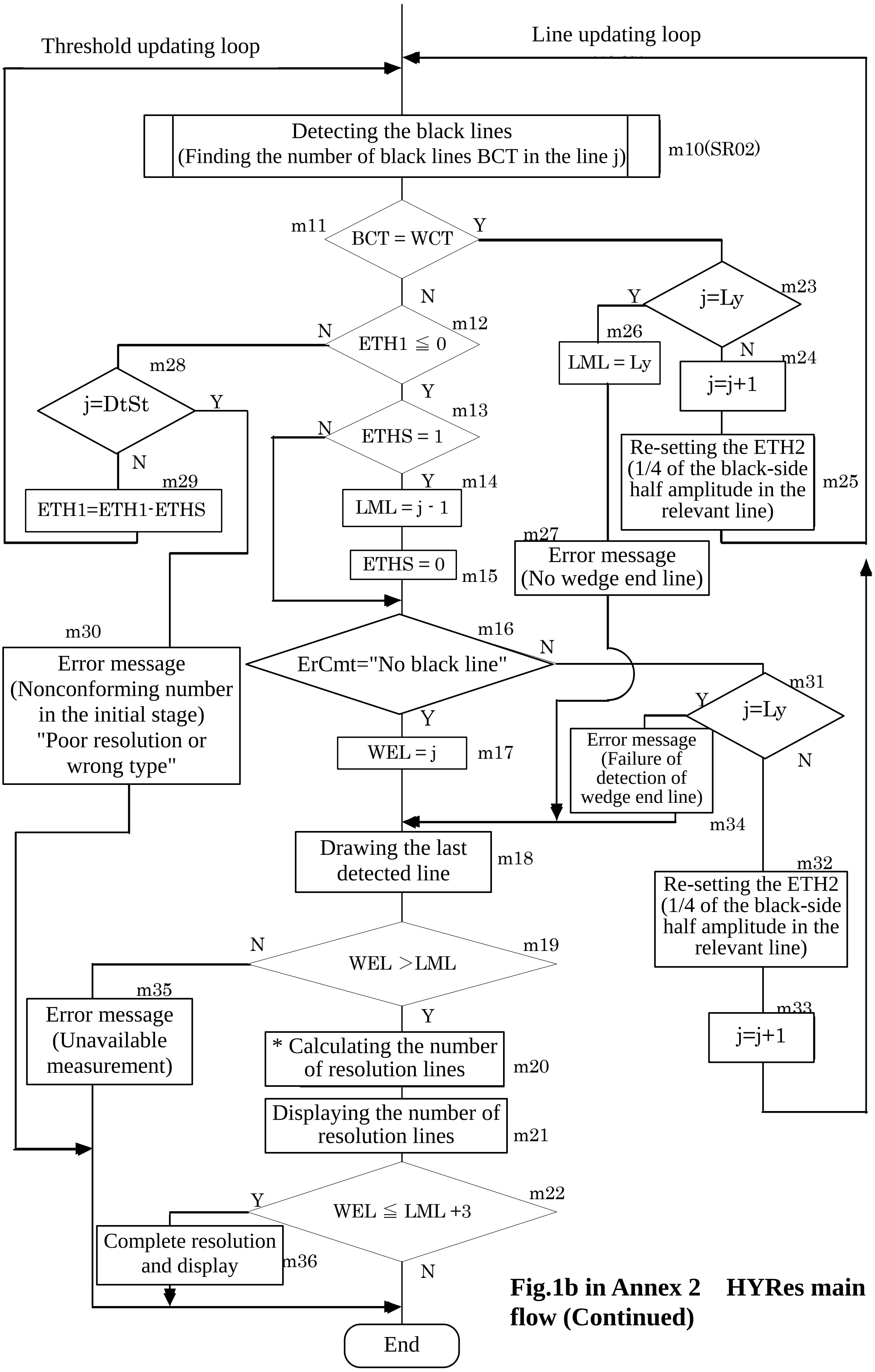


Fig.1b in Annex 2 HYRes main flow (Continued)

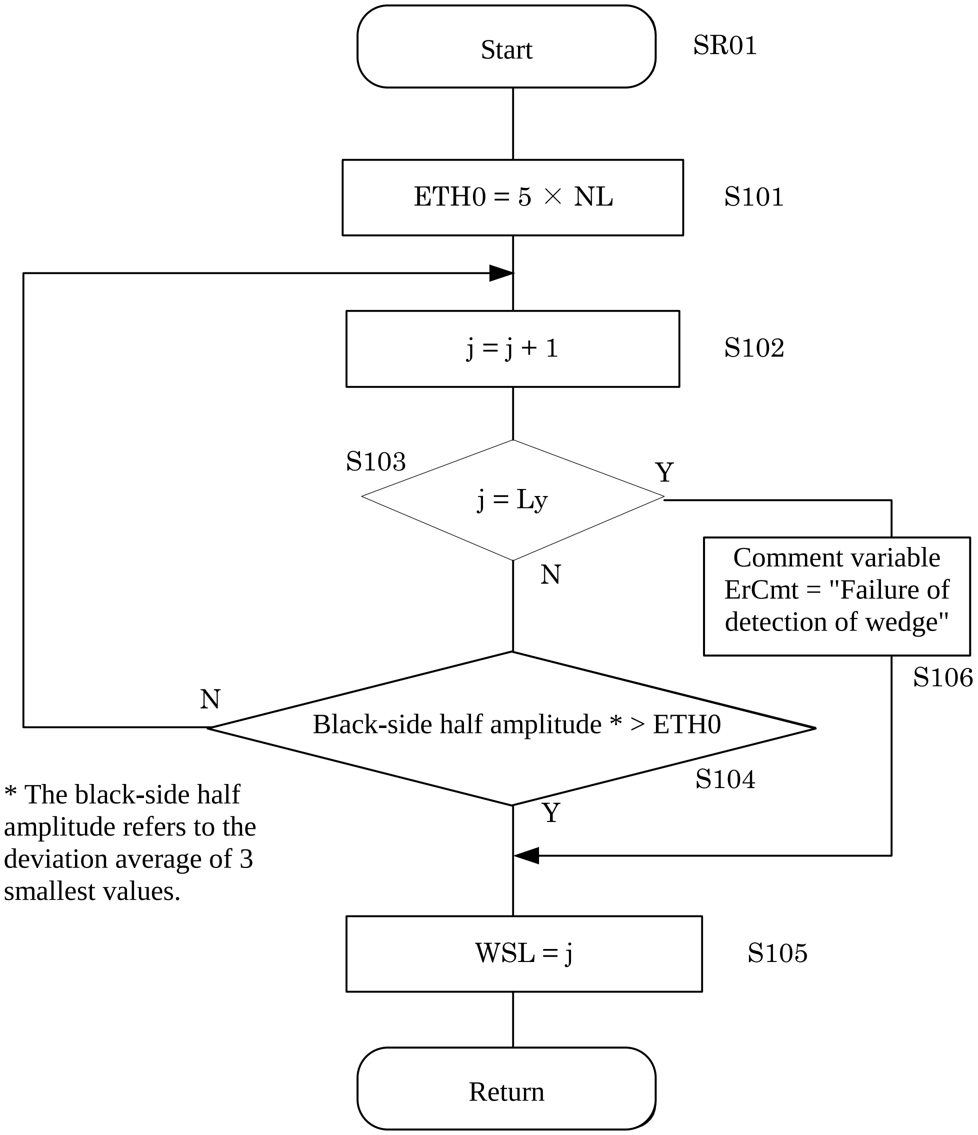


Fig.2 in Annex 2
Sub flow for detection of wedge starting line WSL and the formulas for calculating the number of resolution lines

Formulas for calculating the number of resolution lines

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

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

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

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

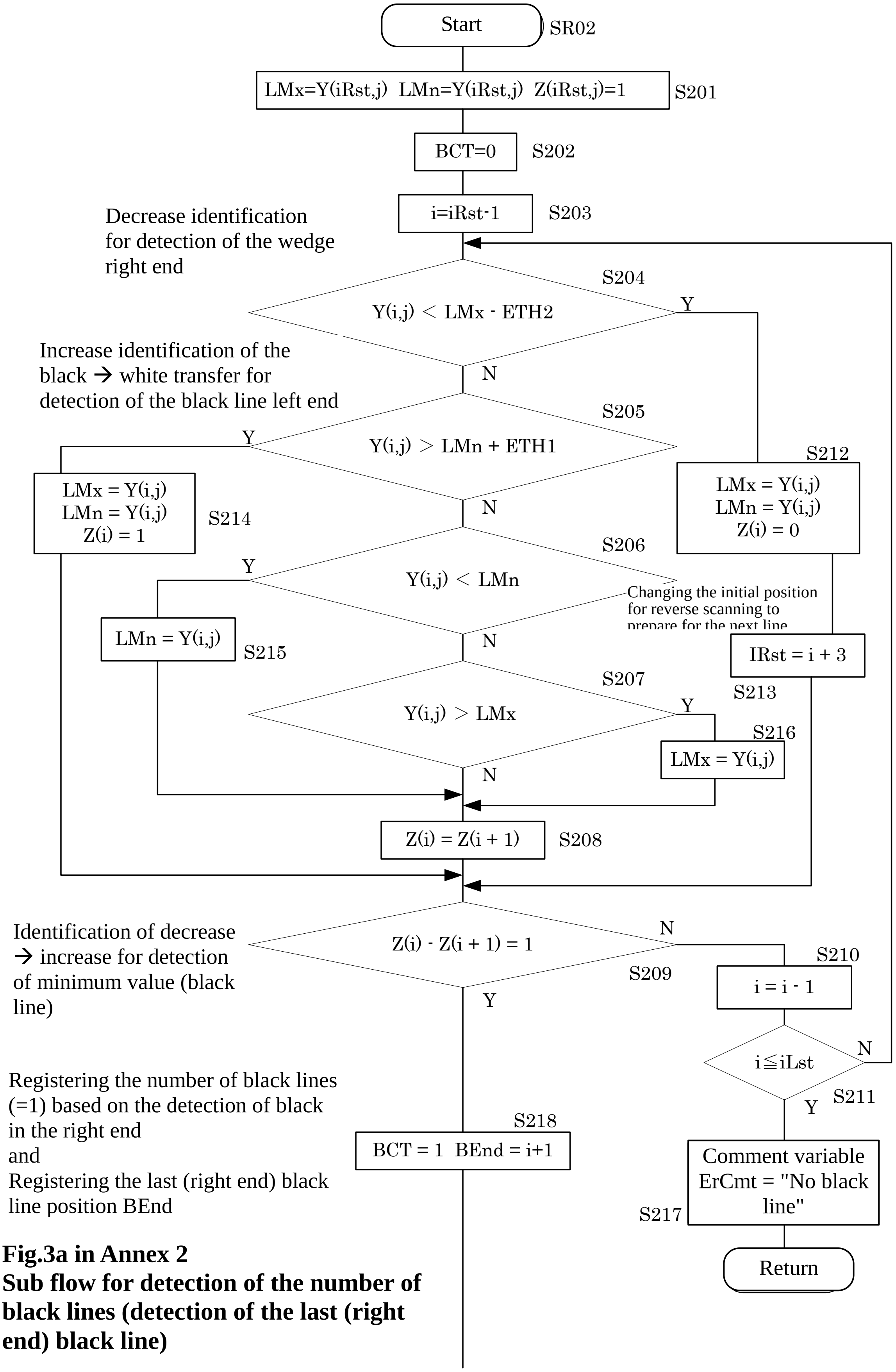


Fig.3a in Annex 2
Sub flow for detection of the number of black lines (detection of the last (right end) black line)

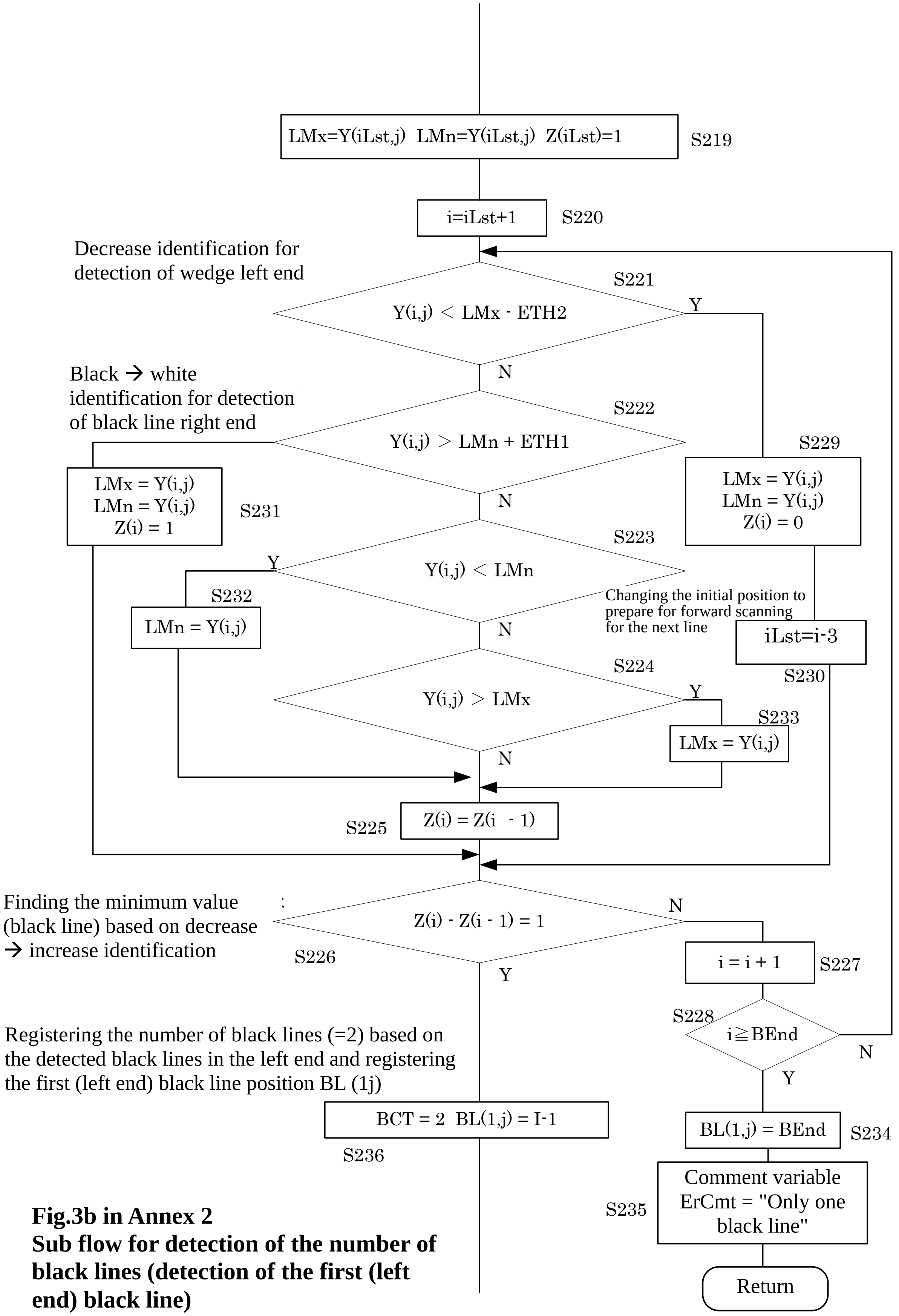


Fig.3b in Annex 2
Sub flow for detection of the number of black lines (detection of the first (left end) black line)

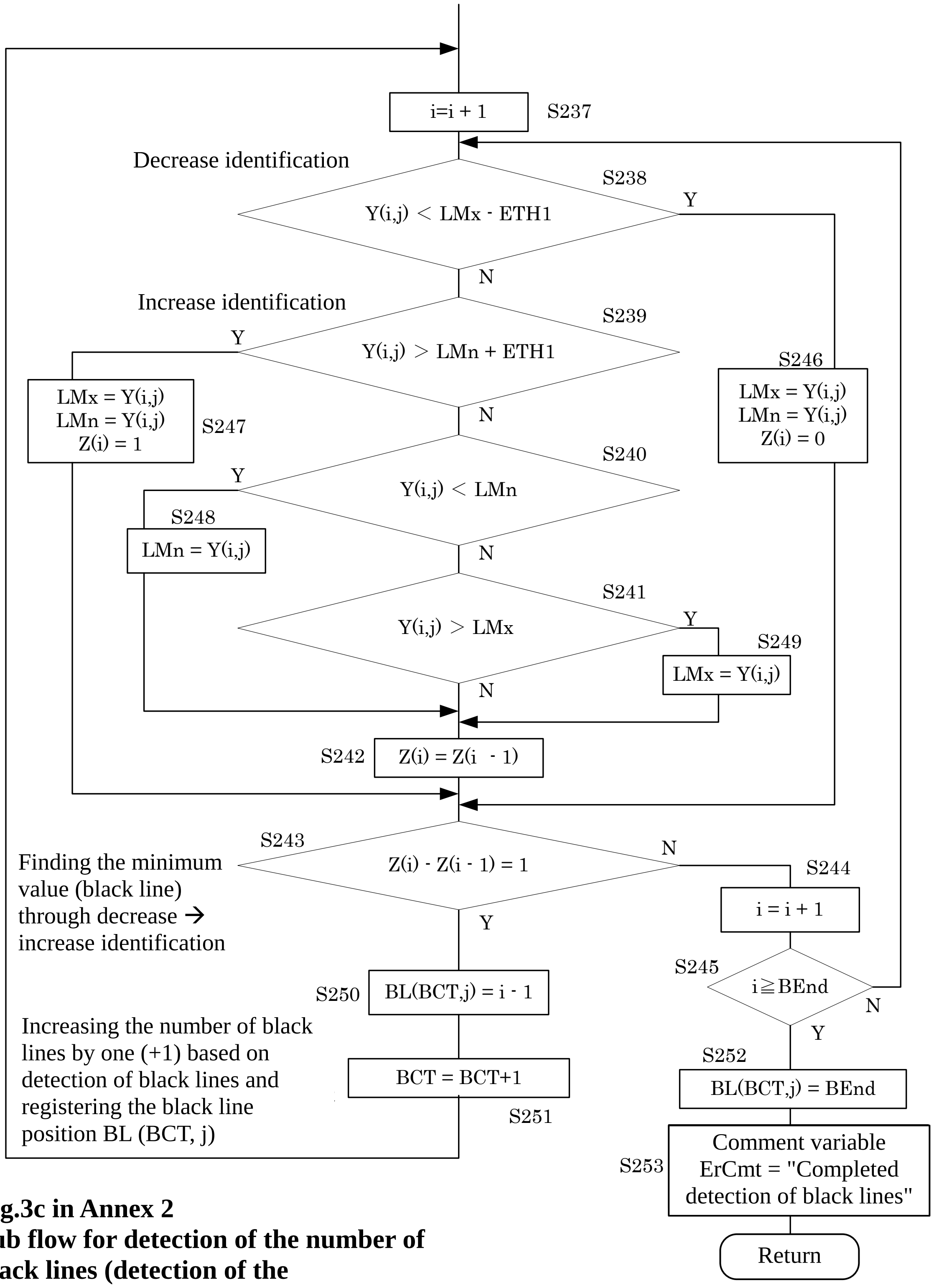


Fig.3c in Annex 2
Sub flow for detection of the number of black lines (detection of the intermediate black lines)

Annex 3 (Informative) The HYRot 45-Degree Image Rotation Software 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).

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

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

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).

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

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

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

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)

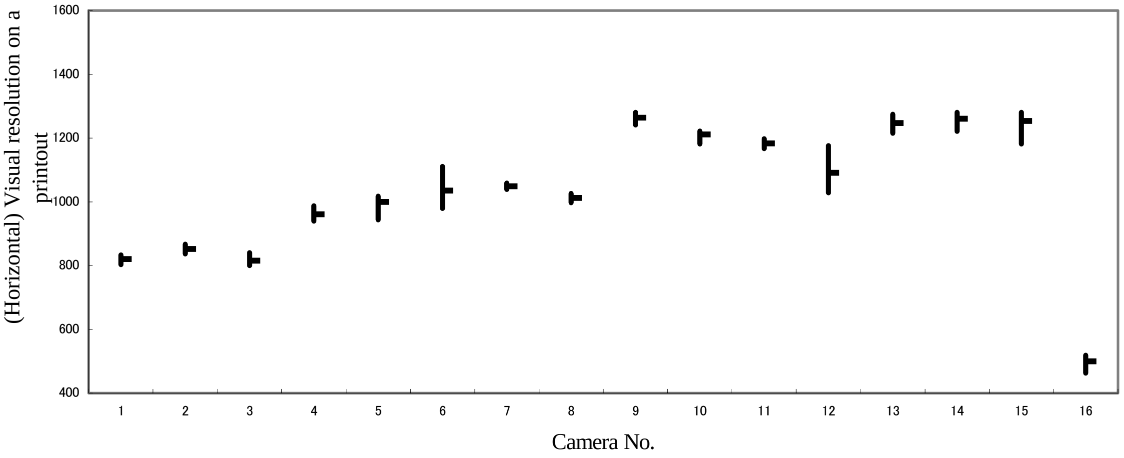
2. Difference between computer software-based and visual resolution measurements

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.

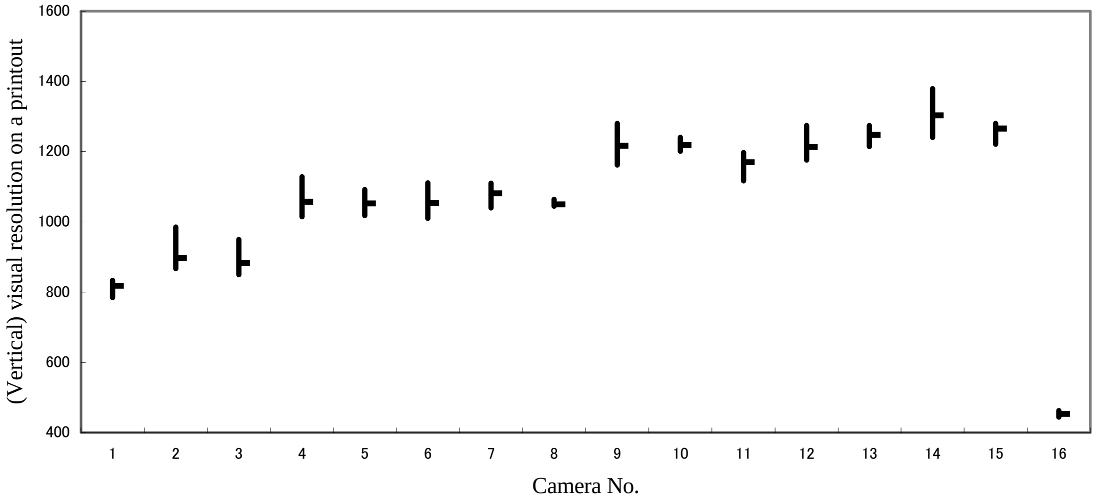
	Average	SD
Horizontal	26.1	16.1
Vertical	19.8	22.8
45-degree diagonal	29.5	19.2

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

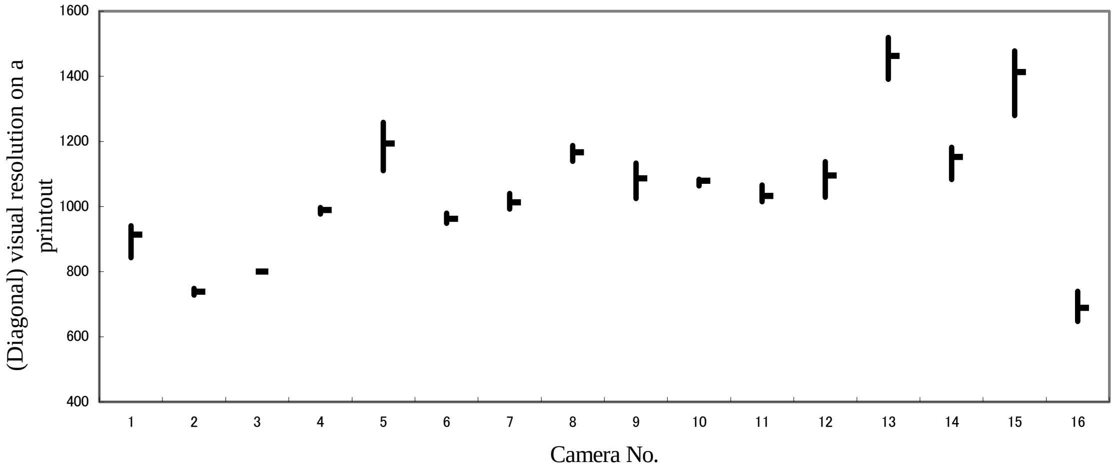
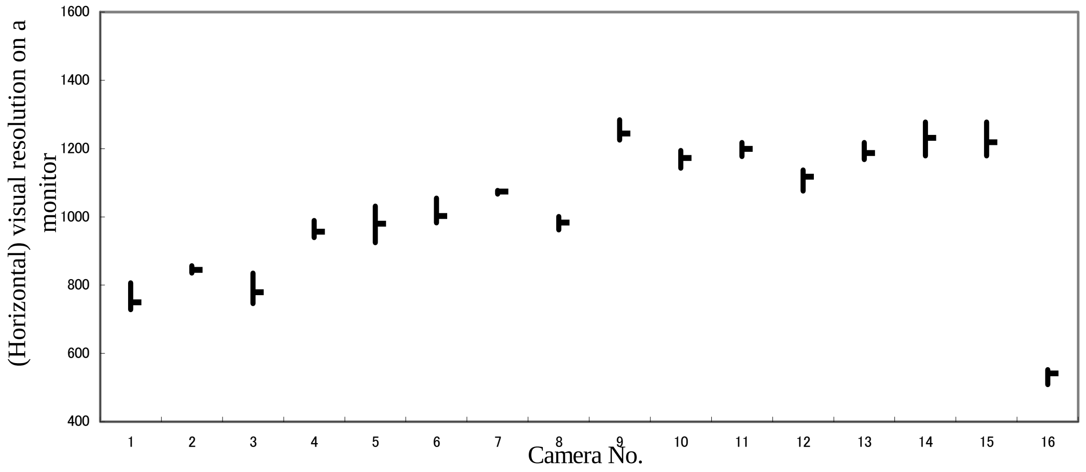
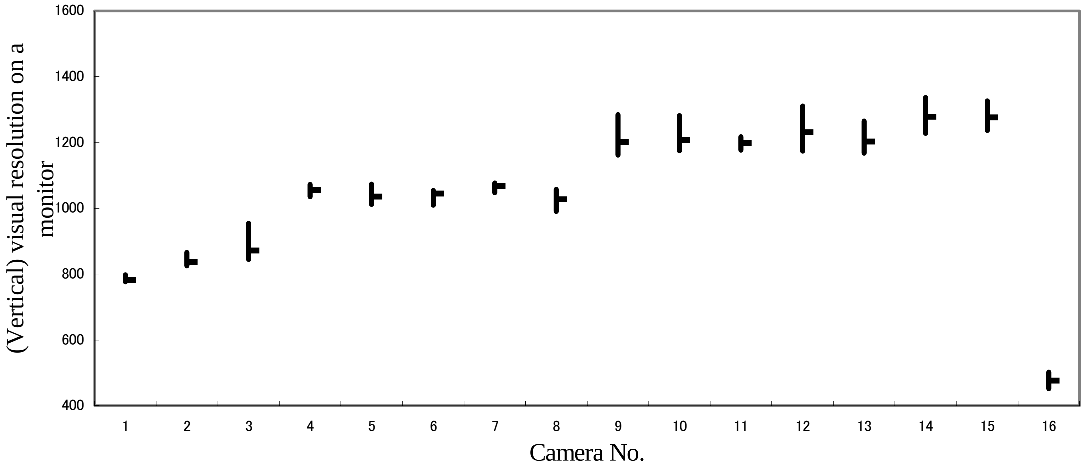


Fig.1 in Annex 4 Variation in the lines of visual resolution on a printout

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



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



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

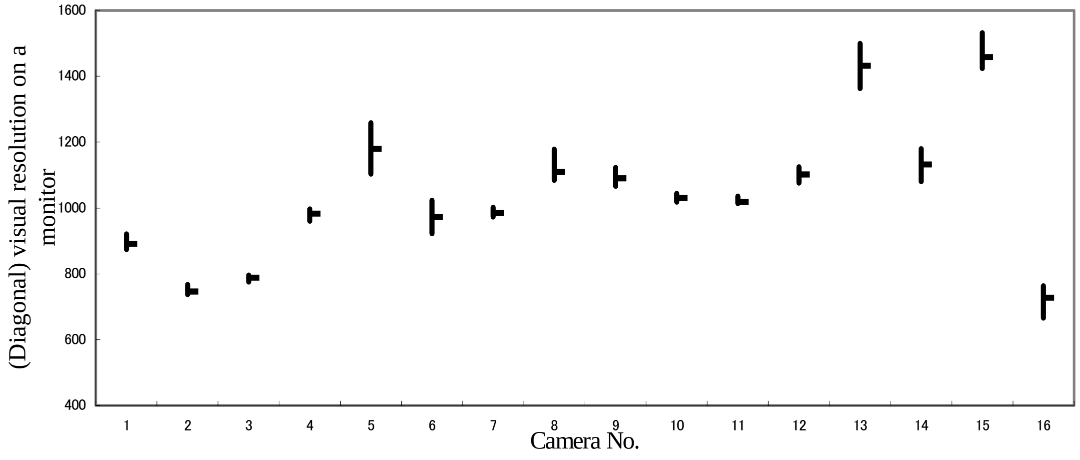
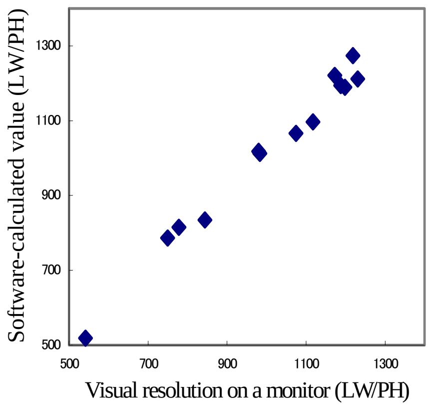
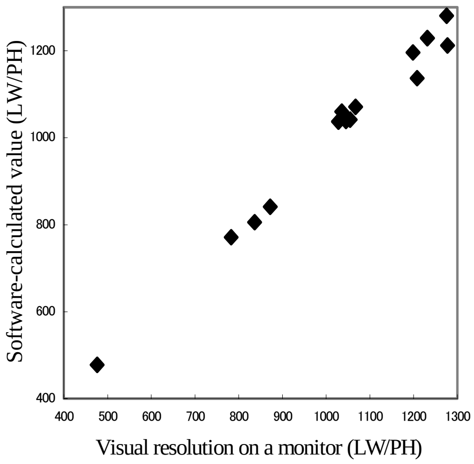


Fig.2 in Annex 4 Variation in the lines of visual resolution on a monitor

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



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



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

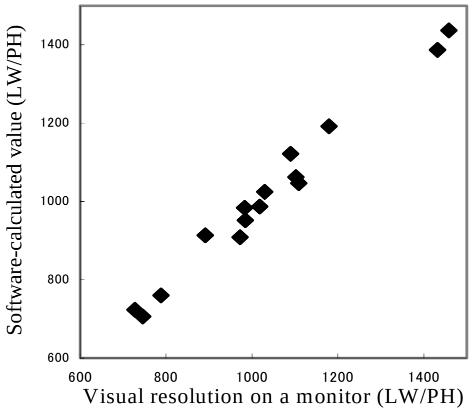


Fig.3 in Annex 4 Visual resolution on a monitor and software-calculated resolution

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.

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 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.

The committees involved in drafting the Standard are as follows:

［Standardization　Committee］

Chair	Iwao Aizawa	KONICA MINOLTA TECHNOLOGY CENTER, INC. (KONICA　CORPORATION)
Vice Chair	Nobuaki Sakurada	Canon Inc.
	Eichi Ichimura	Sony Corporation
	Tetsuro Goto	NIKON CORPORATION
	Toshiharu Iida	Fuji Photo Film Co., Ltd.

[Technical Working Group]

Leader	Kosho Miura	NIKON CORPORATION
Sub Leader	Hideaki　Yoshida	OLYMPUS CORPORATION (OLYMPUS OPTICAL CO., LTD.)
	Tadasu Ohtani	Canon Inc.
	Masaaki Nakayama	Matsushita Electric Industrial Co., Ltd.

[Promotion Working Group]

Leader	Akio Usui	PENTAX Corporation (Asahi Optical Co., Ltd)
Sub Leader	Mitsuo Matsudaira	Canon Inc.
	Michihiro Iwata	KONICA MINOLTA CAMERA, INC. (Minolta Co., ltd.)

［Resolution Sub−Working Group］

Chief	Makoto Tsugita	Fuji Photo Film Co., Ltd.
Sub Chief	Hideaki Yoshida	OLYMPUS CORPORATION (OLYMPUS OPTICAL CO., LTD.)
Member	Yasushi Tanaka	ImageLink, Inc.
	Shigekuni Yanagida	CASIO COMPUTER CO.,Ltd.
	Ichiro Fujii	CASIO COMPUTER CO.,Ltd.
	Koji Sano	CASIO COMPUTER CO.,Ltd.
	Hiroyuki Otsuka	Canon Inc.
	Shinya Tamizu	Kyocera Corporation.
	Hiroyuki Minagawa	Kyocera Corporation.
	Minoru Yahiro	KODAK JAPAN LTD.
	Koichi Settai	KODAK JAPAN LTD.
	Kenpo Tsuchiya	KONICA MINOLTA OPTO, INC. (KONICA CORPORATION)
	Yasushi Hasegawa	KONICA MINOLTA OPTO, INC. (Minolta Co., ltd.)
	Shinji Ukita	SANYO Electric Co., Ltd
	Takafumi Usui	SHARP CORPORATION
	Kohichi Harada	SHARP CORPORATION
	Masanobu Shirakawa	SEIKO EPSON CORPORATION
	Takayoshi Kojima	SEIKO EPSON CORPORATION
	Yoshiyuki Sekine	Sony Coporation
	Naoya Katoh	Sony Coporation
	Shougo Sakuraba	TAMRON CO.,LTD
	Kikuo Tamura	TAMRON CO.,LTD
	Sumio Sakai	TOSHIBA CORPORATION
	Masao Ohnuki	Nikon Corporation
	Yasuhiko Abe	NIDEC COPAL CORPORATION
	Toshiro Kinugasa	Hitachi,Ltd.
	Tetsuya Abe	PENTAX Corporation (Asahi Optical Co., Ltd)
	Shigeo Sakaue	Matsushita Electric Industrial Co., Ltd.
	Yasutoshi Yamamoto	Matsushita Electric Industrial Co., Ltd.
	Tsumoru Fukushima	Matsushita Electric Industrial Co., Ltd.
	Toshihiro. Suzuki	Ricoh Co., Ltd
	Toshiaki Nakahira	Ricoh Co., Ltd
	Akihiro Yoshida	Ricoh Co., Ltd

In addition, the Documentation Rule Sub-Working Group in the Propagation Working Group has collaborated on the consideration of the expressions in this Standard.

［Documentation Rule － Working Group］

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Sub Chief	Mitsuo Matsudaira	Canon Inc.
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	Hiroe Kuboki	OLYMPUS CORPORATION (OLYMPUS OPTICAL CO., LTD.)
	Takashi Niida	CASIO COMPUTER CO., Ltd.
	Atsuhiko Oda	Kyocera Corporation.
	Keiji Arai	KODAK JAPAN LTD.
	Kumi Okabe	KONICA MINOLTA CAMERA, INC. (Minolta Co., ltd.)
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	Masanobu Shirakawa	SEIKO EPSON CORPORATION
	Masako Yamada	SEIKO EPSON CORPORATION
	Kesahiro Miyazawa	SEIKO EPSON CORPORATION
	Mie Kobayashi	Sony Corporation
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	Hajime Akiyama	TOSHIBA CORPORATION
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CIPA DC003-Translation-2003

Published in December, 2003

Published by Camera &Imaging Products Association
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