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Graphic technology — Image quality evaluation methods for printed matter —

Part 31: Evaluation of the perceived resolution of printing systems with the Contrast–Resolution chart

Technologie graphique — Méthodes d'évaluation de la qualité d'image pour les imprimés —

Partie 31: Évaluation de la résolution perçue des systèmes d'impression avec un graphique de contraste–résolution

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Foreword

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This document was prepared by Technical Committee ISO/TC 130, *Graphic technology*.

A list of all parts in the ISO 18621 series can be found on the ISO website.

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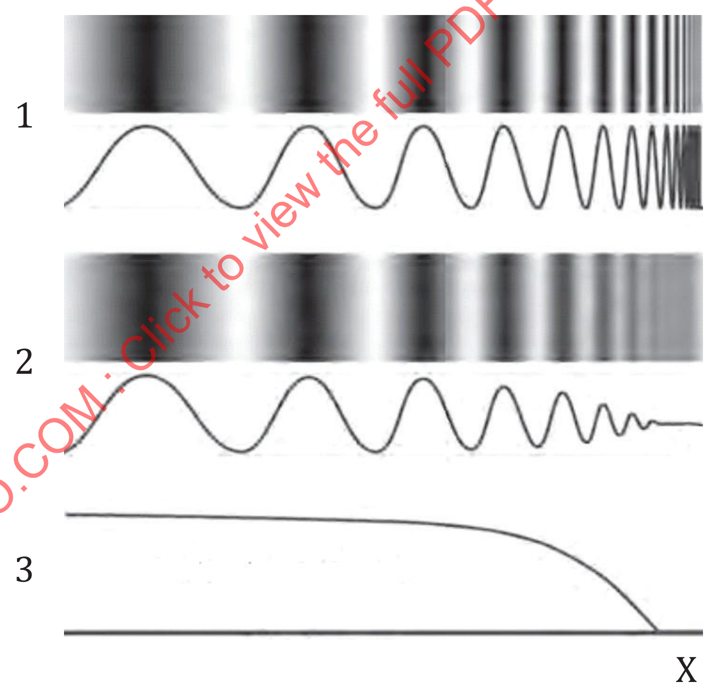
Introduction

Perceived resolution, the capability to perceive fine detail, is a measure of full system capability and depends upon characteristics of the printing system (substantially more than just its addressability), characteristics of the substrate, of the viewing conditions, and of the observer. Perceived resolution depends critically upon tonal differences between elements of an image – there is no perceived detail, hence no measure of resolution, when there is no tonal difference in an image. The three major contributors to the perceived resolution of a printing system are the capability of a printing system to maintain a desired spatial separation between nearby elements printed on a substrate (the addressability of a printing system indicates what the minimum spatial separation can be), the capability of the printing system to carry tonal differences (contrast) between these nearby printed elements, and the capability of the human visual system to perceive the printed detail. The design of a test chart and an evaluation process for measuring a printing system's capability to carry fine detail must reflect these major contributors.

Fourier analysis has proven very useful in analysing the reproduction capability of image forming systems[1]. In this formalism, spatial separation is measured in terms of spatial frequency (e.g. cycles per millimetre) and contrast is measured in terms of modulation (the dimensionless ratio of a change in perceived luminance to its average luminance) at a particular spatial frequency. The ratio of the reproduced modulation to the original (desired) modulation can be used to describe the capability of a printing system to reproduce a sinusoidal input at a particular spatial frequency. This ratio, taken over a range of spatial frequencies is called the modulation transfer function (MTF).



Key

X spatial fequency

1 modulation of original (constant amplitude)

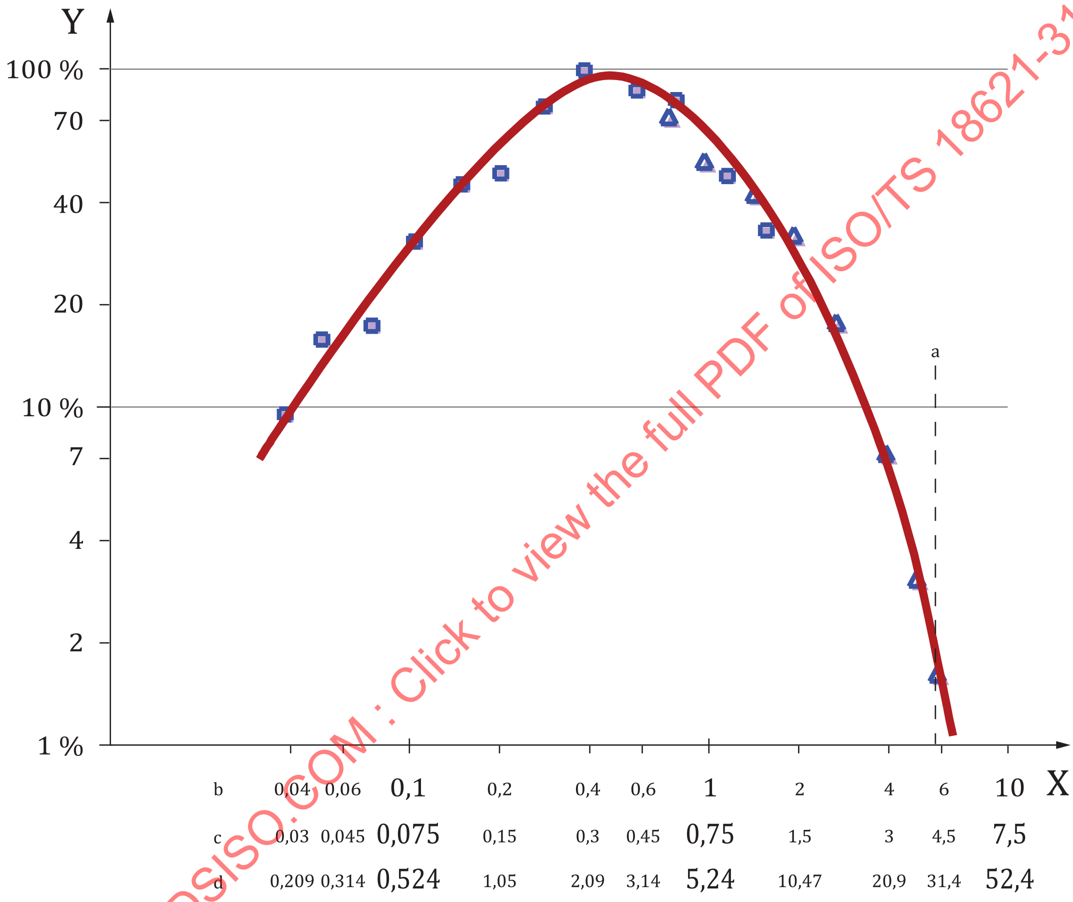
2 modulation of reproduction (with limited resolution)

3 modulation transfer function (decreases due to limited resolution)

Figure 1 — Modulation transfer function of a printing system

The MTF characteristic shows the ratio of the reproduced modulation to the original (input) modulation as a function of spatial frequency and provides a very useful description of printing system capability. The decrease at high frequencies of the modulation transfer function shown in Figure 1 characterizes the common degradation in printing system image detail capability at high spatial frequencies.

In characterizing perceived resolution, a single component of the imaging chain cannot be isolated since we look at the results of the complete system. The printing system imaging chain starts with the process of placing marks on a substrate. In many printing systems, the individual marks can provide only a limited number of tonal levels and the full tonal range is provided by subsequent area modulation (screening) of the marks. This screening process can strongly affect the image detail capability of a printing system. The characteristics of the substrate can affect both the effectiveness of placing these marks (e.g. surface roughness) and affect the interplay between the placed marks and the illumination required for viewing the printed image (e.g. light scattering in the substrate). Finally, perceived resolution depends upon the viewing conditions (illumination, viewing distance, and magnification) as well as the capability of the human observer to perceive detail. The capability of normal human vision to perceive spatial detail can be characterized by a modulation transfer function (see Reference [2]). This is shown in Figure 2.



Key

Y relative contrast sensitivity

X spatial frequency

[a] 6/6 visual limit

[b] cy/mm at 300 mm

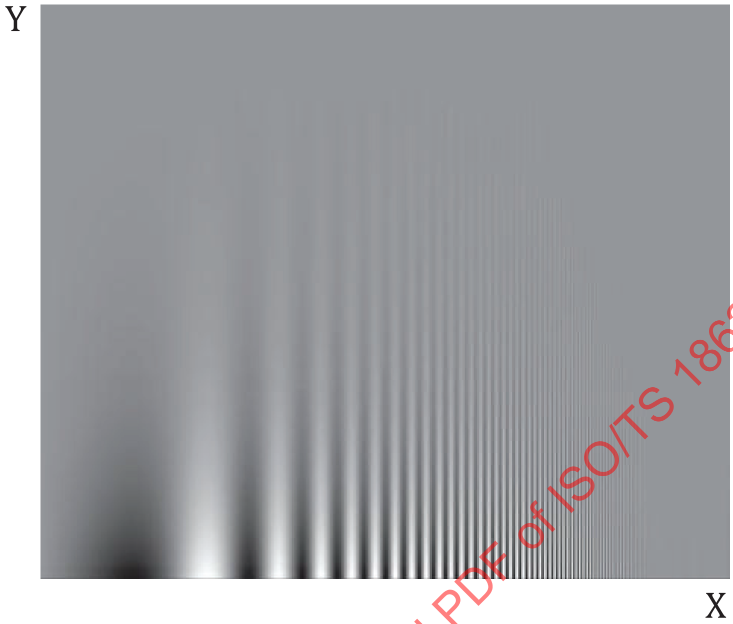
[c] cy/mm at 400 mm

[d] cy/degree

Figure 2 — Contrast sensitivity function of a human observer

The natural units for the perceptual contrast sensitivity function are cycles per degree, which are independent of viewing distance. Shown as a dotted line on the right of Figure 2 is the ophthalmological limit of visual acuity known as 6/6 vision in metric units which means a person being examined can see the same level of detail at 6 m as a person with "normal" visual acuity would see at 6 m distance. This visual limit corresponds to a spatial frequency of about 6 cy/mm at 300 mm viewing distance or about

4,5 cy/mm at a viewing distance of 400 mm. At a viewing distance of 400 mm the human visual system response to spatial detail peaks at about 0,4 cy/mm (0,5 cy/mm at 300 mm), decreasing in sensitivity at both higher and lower spatial frequencies.



Key

Y contrast

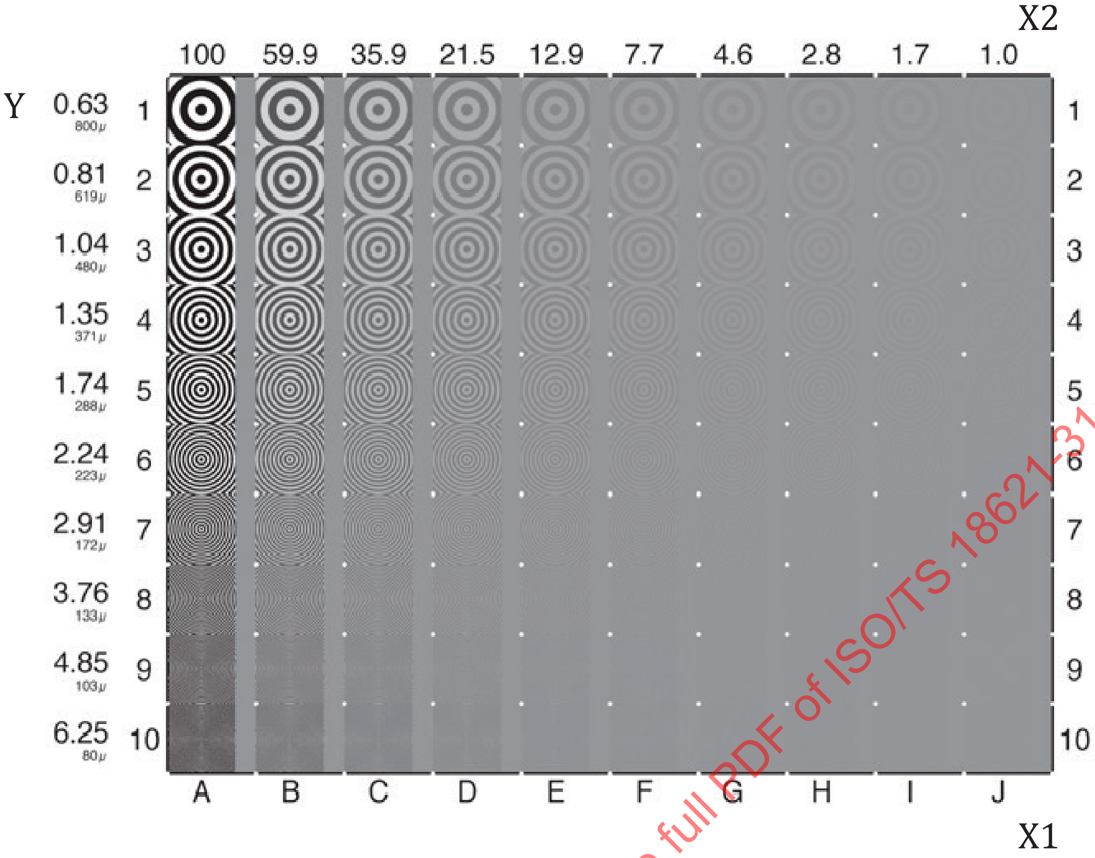
X spatial frequency

Figure 3 — Illustrative contrast sensitivity function (Reference [3])

A visual illustration of the dependence of perceptual detail reproduction capability on both spatial frequency (horizontal axis) and contrast (vertical axis) is shown in Figure 3 (see Reference [3]). The perception of fine detail is frequency dependent and can be perceived well at high contrast, but not as well at low contrast.

For given viewing conditions (illumination, viewing distance, magnification), measurements at extreme spatial frequencies are irrelevant to the characterization of the perceived resolution of a printing system as their effects cannot be seen (e.g. the far right side of Figure 2 or Figure 3).

The illustration shown in Figure 3 also illustrates the peak in visual sensitivity in the mid spatial frequency range and is a major motivation for the test chart design utilized in this method for evaluating the perceived resolution of a printing system. A test chart that explores modulation or contrast along one axis and spatial frequency along an orthogonal axis covers a large fraction of the major contributors to the perceived resolution of a printing system. Figure 4 shows the Contrast–Resolution test chart[4].



Key

Y resolution, line pairs per millimetre, log steps

X1 contrast

X2 reference tone value = 50%

NOTE Reproduced with permission from Sicofilm A.G.

Figure 4 — Elements of the Contrast–Resolution test chart

In Figure 3, contrast and spatial frequency vary continuously. In Figure 4, each circularly symmetric element explores a particular sampled contrast and spatial frequency – the individual patches in the target. The spatial frequency of separation of these circularly symmetric marks and spaces in each patch is varied logarithmically along the vertical axis of the target and the contrast, or depth of modulation, is varied logarithmically along the horizontal axis. This logarithmic spacing mimics the largely logarithmic response characteristics of the human visual system. This representation of contrast vs. spatial frequency resembles the Campbell and Robson illustration flipped on its side. The circularly symmetric shape, and the range of values explored in the Contrast–Resolution test chart are well suited to the characterization of digital printing workflows.

In a conventional printing system, there are processes at four spatial frequencies that interact with each other to form an image on the substrate. The first frequency is the spatial frequency of detail in an imaged scene (this is represented by the vertical axis of the Contrast–Resolution test chart). The second spatial frequency is the sampling frequency of the pixel grid in the digital image to be reproduced. The Contrast–Resolution test chart shown in Figure 4 is vector based, not a bitmap, therefore there are no image pixels. The third spatial frequency is the addressability grid of the printing device. The printing system raster image processor (RIP) maps the image pattern to the addressability grid and then decides, for each individual addressability location, how to image that spot. For a binary printing device (e.g. offset or flexo printing), the spot is either turned on or off. For a non-binary output device (e.g. some electrostatic or inkjet systems), where the output spots can be imaged at more than one gray level, the RIP also determines at which gray level the output spot needs to be imaged. These individual spots are utilized by the RIP to build the screening pattern that carries the tone scale of the image. The spatial repetition frequency of this screen is the fourth frequency in this printing process. All of these frequencies have the potential to interfere with one another, and hence have the potential to introduce moiré.

The Contrast–Resolution test chart was designed for visual evaluation. Evaluation starts at the top of column A (lowest spatial frequency and highest contrast) and moves down the target towards higher spatial frequencies – note how a moiré pattern gradually develops between the circular lines and addressability grid of the printer. The observer is tasked to find, for each column of the target, the patch at the highest spatial frequency at which the circular lines in the patch are still recognizably reproduced – where no lines or spaces are missing or overlap and where the level of moiré interference does not obscure the circles. For each column in the target, an index value that is the row number (each row is a single spatial frequency) of the last recognizable patch is recorded. This operation maps the threshold curve along columns in the Contrast–Resolution target where circular elements are no longer recognizable. The area enclosed by this threshold curve can be used as a capability score for the printing process. In observation, the circular nature of the lines in each pattern tends to average out any angular dependencies in system resolution.

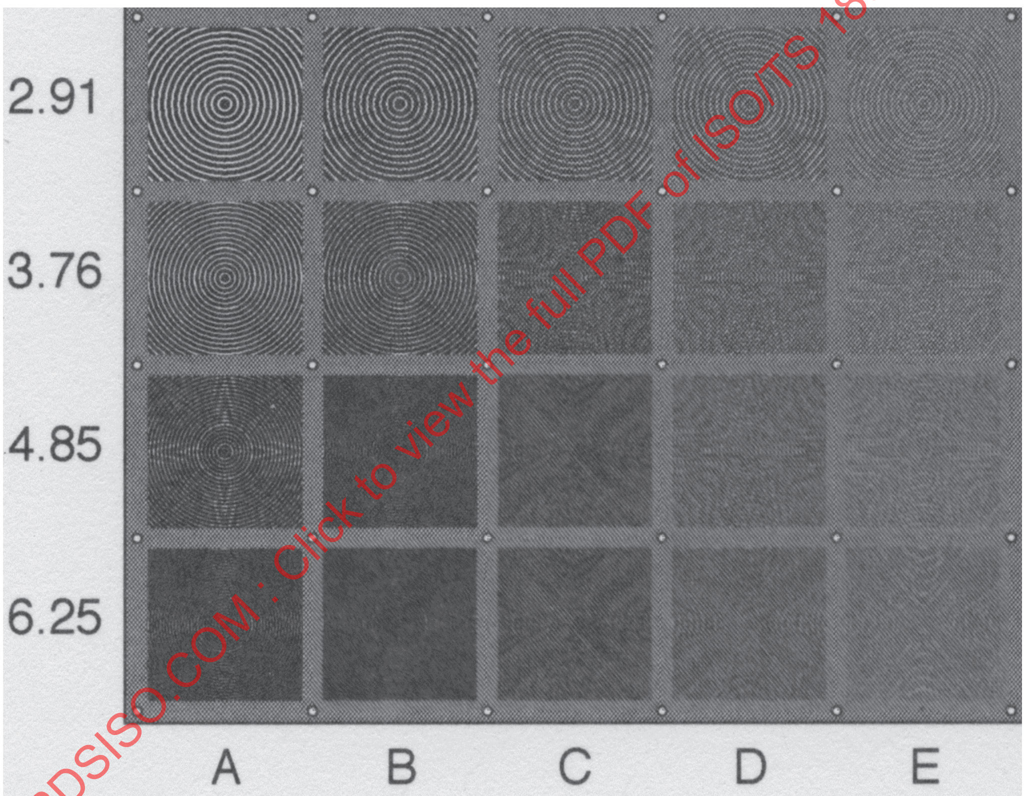


Figure 5 — Enlarged portion of a Contrast–Resolution target print

Figure 5 shows an enlarged portion of a print made with a 1 200 spot per inch addressability, utilizing a 133 line per inch dot screen. The circular patterns of the 2,91 cy/mm Row in Columns A through E are clear. The circular patterns of the 3,76 cy/mm Row in Columns A and B are clear, but are not legible in Columns C, D or E. The circular pattern of the 4,85 cy/mm Row in Column A is present with some aliasing. The circular pattern of the 6,25 cy/mm Row in Column A is barely legible with significant aliasing. The resolution capability of this printer configuration degrades significantly as the contrast is lowered – none of the other patches in Figure 5 shows a recognizably circular pattern. An illustration of an index value threshold curve (white line) and its enclosed area (above the white line) is shown in Figure 6.

The procedure specified in this document provides an automated, objective measurement surrogate of the detailed visual examination process previously used in the evaluation of the Contrast–Resolution test chart. The initial form of this procedure, developed by Liensberger[5], provided a single valued score (L-score) that correlated well with subjective impression, based upon the area of a threshold curve derived from normalized cross-correlation coefficients. A refinement of this automated procedure proposed by Uno and Sasahara[6] and called resolution-score forms the basis for this document. An international verification test was conducted, involving both objective measurements, using this improved procedure, and subjective evaluation of Contrast–Resolution test charts printed with a variety of printing systems. These experiments showed very good correlation of objective measurements with subjective evaluations using the improved resolution-score procedure.

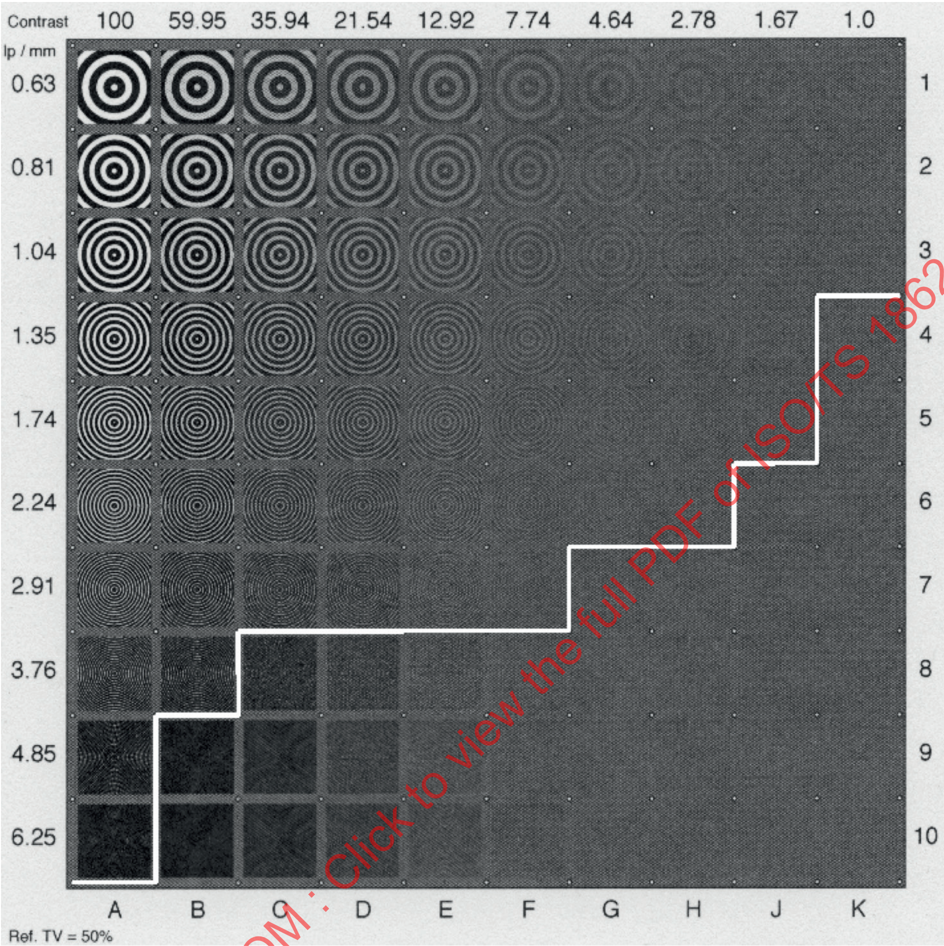


Figure 6 — Enclosed area above an index value threshold curve

Both objective measurement and subjective evaluation of Contrast–Resolution test charts printed with process colorants are minimally affected by the low levels of colorant mis-registration present in modern, well maintained printing systems. The level of colorant mis-registration in printed test charts should be verified to be low when utilizing the procedure specified in this document with process color printing.

Clause 4 specifies the requirements of the workflow settings needed to effectively print the Contrast–Resolution test chart, the setup requirements of the printer utilized to reproduce these test charts, the requirements of the scanner characteristics needed to effectively digitize the information reproduced on the printed test charts, and the requirements of the scanner data processing path needed to properly represent this information for automated evaluation.

Clause 5 specifies the resolution-score measurement procedure.

Clause 6 specifies the reporting of results obtained with the process specified in Clause 5.

Graphic technology — Image quality evaluation methods for printed matter —

Part 31: Evaluation of the perceived resolution of printing systems with the Contrast–Resolution chart

1 Scope

This document specifies the Contrast–Resolution test chart, the requirements on the printing process needed to reproduce this test chart, the required characteristics of a high resolution scanner needed to digitize the information reproduced on printed test charts, and the requirements on the interpretation of this digitized data. It also specifies the resolution-score method for evaluating the perceptual resolution of printed material using the Contrast–Resolution test chart.

The procedure specified in this document is intended for a characterization of the perceived resolution of a graphic arts production printing system using the Contrast–Resolution test chart.

2 Normative references

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

ISO 5 (all parts), *Photography and graphic technology — Density measurements*

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

ISO 13655, *Graphic technology — Spectral measurement and colorimetric computation for graphic arts images*

ISO 16067-1, *Photography — Spatial resolution measurements of electronic scanners for photographic images — Part 1: Scanners for reflective media*

3 Terms and definitions

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

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

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

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

3.1
aliasing
output image artifacts that occur in a sampled imaging system for input images having significant energy at frequencies higher than one half the spatial sampling frequency of the system

3.2
luminance factor
CIE Y
Y
dimensionless ratio of the luminance of the surface element, in the given direction, to that of the perfect reflecting diffuser identically illuminated and viewed

Note 1 to entry: It is defined by the CIE and denoted as CIE Y.

Note 2 to entry: The luminance factor of the perfect reflecting diffuser identically illuminated is 100.

3.3
CIE L*
L*
metric lightness
function of luminance factor, defined by the CIE which approximates the human visual system response to achromatic stimuli.

Note 1 to entry: For luminance factors greater than 0.008856, $L^* = 116(Y/Y_n)^{1/3} - 16$. For luminance factors less than or equal to 0,008 856, $L^* = 903{,}3\ (Y/Y_n)$.

Note 2 to entry: Y_n is the luminance factor of a white achromatic reference, typically the perfect reflecting diffuser.

3.4
ICC profile
International Color Consortium's file format used to store transforms from one colour encoding to another, e.g. from device colour coordinates to profile connection space, as part of a colour management system

Note 1 to entry: The colour management system is standardized as ISO 15076-1[7].

3.5
modulation
difference between the minimum and maximum signal levels divided by the sum of these levels

3.6
modulation transfer function
MTF
ratio, as a function of spatial frequency, of the measured modulation response in a print produced by a printing system, to the stimulus modulation presented to that printing system

3.7
opto-electronic conversion function
OECF
relationship between the input levels and the corresponding digital output levels for an opto-electronic digital image capture system

3.8
perceived resolution
subjective impression of the capability of an imaging system to depict fine detail

3.9
reflectance factor
dimensionless ratio of the radiant or luminous flux reflected in the directions delimited by the given cone to that reflected in the same directions by a perfect reflecting diffuser identically irradiated or illuminated

3.10
resolution
measure of the ability of a digital imaging system to depict fine detail

3.11
scanner dynamic range
difference of the maximum density where the incremental gain is higher than 0,5 and the minimum density that appears unclipped

Note 1 to entry: The dynamic range is determined according to ISO 21550.

4 Requirements

4.1 General

The method specified in this document provides an evaluation of the fine detail carrying capability of a printing system comprising both workflow and printing that correlates with perceived resolution. Sample prints of the Contrast–Resolution test chart, ISO_ConRes20[1)], produced by a printing system are scanned by a high resolution scanner. Evaluation of the fine detail carrying capability of the printing system is done by comparing these high resolution scans of the Contrast–Resolution test chart prints with a defined reference. Effective practice of this method places requirements on both the printing system and the scanning system. This method can be applied to most printing technologies and substrates.

4.2 Apparatus requirements

4.2.1 Printing system requirements

Effective interpretation of the Contrast–Resolution test chart depends upon printing a set of sample prints of Contrast_Resolution test chart with minimal mis-registration between the different colorants that may be utilized in the printing process. This requirement is conventionally met by either printing the single colorant version of the Contrast–Resolution test chart using a single separation colorant, or by using the well controlled registration of a modern, well maintained, colour managed process colour printing system to print one of the process colour versions of the Contrast-Resolution test chart. Refer to Annex B and Annex C for details.

4.2.2 Scanning system requirements

In the evaluation method specified in this document, a high resolution scanning system is utilized as a surrogate for a human observer. This imposes strict requirements on the setup, calibration and performance of the scanning system used in the evaluation process. In simplest form, the measurement device shall be calibrated and able to accurately capture luminance factor (CIE Y) or lightness information (CIE L*) at a high optical resolution. A scanning system with a useful optical resolution of 1 200 ppi in both the horizontal and vertical direction is required. If the Contrast–Resolution test chart has been printed on a structured substrate, multi-directional illumination is required to minimize shadowing. A scanning system shall conform to the specifications defined in Annex D.

4.3 Procedure

4.3.1 Test chart

The exact procedure specified in this document for evaluating perceived printing system resolution depends upon the structure of the printing system workflow that is being assessed and the objective of the assessment. Evaluation intents are specified in this document to assess the different workflow structures and to meet the objectives of printing application and engineering assessments. Each of these specified evaluation intents utilize one of three colour encoding variants of the Contrast-Resolution

1) The Contrast-Resolution test chart files are provided in the URN: https://standards.iso.org/iso/ts/18621/-31/ed-1/en/.

test chart to properly assess the resolution capability of a printing system. The three colour encoding variants of the Contrast-Resolution test charts[2)] are defined in Annex A and are summarized here:

a) ISO_ConRes20_SepK.pdf which is intended for single colorant (black) resolution capability evaluation.

b) ISO_ConRes20_sRGB.pdf which is intended for process colour resolution capability evaluation.

c) ISO_ConRes20_Lab.pdf which is intended for resolution capability evaluation utilizing the optional linearization process defined in Annex C.

4.3.2 Evaluation intent

Six different evaluation intents are specified in this document for the evaluation of the perceived resolution of different printing system workflows and assessment objectives; four are further specified in Annex B and two are further specified in Annex C. Each of these different evaluation intents defines a process that specifies the appropriate colour encoding variants of the Contrast-Resolution test chart, defined in Annex A, required to properly assess the resolution capability of the printing system workflow. The discussion here and the summary of evaluation intents provided in Table 1 are intended to aid in selecting the appropriate intent.

1) **Device-specific evaluation** of a printing system. This evaluation process is primarily for engineering evaluation of the resolution capability of a single printing system in different printing setup conditions, using a single conforming reflection scanning system. Repeatability is dictated by the printing system stability. Device-specific evaluation may use any of the Contrast-Resolution test chart colour encoding variants.

2) **Single colorant evaluation** of inherent resolution capability, where the printing system workflow is set up to provide a rendition of the single colorant ISO_ConRes20_SepK.pdf[3)] version of the Contrast-Resolution test chart using a single colorant, usually only the black colorant. This evaluation process avoids any resolution degradation due to the mis-register of multiple colorants and aligns with the perceived resolution capability of a printing system when printing text content or black and white graphics. Further discussion is found in Annex B.

3) **Process color evaluation** of practical resolution capability, where the printing system workflow is set up to provide a colour managed rendition of the ISO_ConRes20_sRGB.pdf[4)] Contrast-Resolution test chart that is printed with multiple process colorants, usually with a "rich" black. This setup closely aligns with the perceived printing system resolution capability when printing image content. Further discussion is found in Annex B.

4) **Standardized process colour evaluation** of the resolution capability of a printing system set up to simulate a standardized printing application, e.g. commercial printing, packaging or newsprint. This evaluation process relies on the standard printing application ICC profiles available from www.ECI.org to provide the defined color reproduction aims of a standardized printing system workflow of commercial interest. Standardized process colour evaluation uses colour managed interpretation of the sRGB encoded version of the Contrast-Resolution test chart, ISO_ConRes20_sRGB.pdf, and is particularly useful in the comparison of different printing systems

5) **Linearized single colorant evaluation** of printing system resolution capability. Linearization maximizes the information content of the test chart through the printing process and the analysis of the resolution capability of a printing system but utilizes a tone-scale that is not representative of normal printing operations. This evaluation process utilizes the single colorant version of the Contrast Resolution test chart, ISO_ConRes20_SepK.pdf[2)], and is aimed at engineering assessment

2) The Contrast-Resolution test chart files are provided in the URN: https://standards.iso.org/iso/ts/18621/-31/ed-1/en/.

3) The corresponding files are provided in the URN: https://standards.iso.org/iso/ts/18621/-31/ed-1/en/.

4) This PDF file is provided in the URN: https://standards.iso.org/iso/ts/18621/-31/ed-1/en/.

of the ultimate resolution capability of a single colorant in a printing system. Further discussion is found in Annex C.

6) **Linearized process colour evaluation** of printing system resolution capability. Linearization maximizes the information content of the test chart through the printing process and the analysis of the resolution capability of a printing system but utilizes a tone-scale that is not representative of normal printing operations. This evaluation process utilizes the CIELab encoded Contrast Resolution test chart, ISO_ConRes20_Lab.pdf[5)], and is aimed at engineering assessment of the ultimate resolution capability of a process colour printing system. Further discussion is found in Annex C.

Table 1 — Comparison of evaluation intents

Evaluation intent	SepK	sRGB	Lab	Single colorant	Process color	Linearization	Printing applications	Engineering	Purpose
(1) Device-specific	X	X	X	X	X	N/A	X	X	Compare printer configurations. Restricted to a single printing system.
(2) Single-colorant	X			X		No	X		Single colorant printing. Text, Line-art and B&W reproduction.
(3) Process-colour		X			X	No	X		Normal operation of a printing system. Photographic reproduction market.
(4) Standardized process-colour		X			Standardized	N/A	X		Compare different printing systems.
(5) Linearized single-colorant	X			X		External		X	Maximum resolution capability of single colorant printing.
(6) Linearized process-colour			X		X	Inherent		X	Maximum resolution capability of process-color printing.

Users of this document shall take careful note of the image structure in printed Contrast-Resolution test charts to verify that the test charts are printed according to the desired evaluation intent.

4.3.3 Printing and scanning

Print a set of at least two sample prints of the appropriate Contrast–Resolution test chart, defined in Annex A, for the appropriate evaluation intent according to the printing system requirements specified in Annex B and Annex C. Discard the first, warm-up, print. Ensure that no geometric scaling is applied (the box around the test chart should be square with sides of 109,7 mm.). For example, "Scale to page" should be set to "No Scaling" and "Magnification" should be set to "100 %". In general, any spatial enhancement applied in the printing of the assessment test chart will distort the evaluation of printing system resolution and should be avoided. For example, "Sharpen" or "Unsharp Mask" should be set to "None" in the workflow used to print the Contrast-Resolution test chart. For an accurate evaluation of a printing system and its workflow, the printing system should be configured as it is intended to be used.

5) The Contrast-Resolution test chart files are provided in the URN: https://standards.iso.org/iso/ts/18621/-31/ed-1/en/.

Scan the sample prints of the Contrast–Resolution test chart produced in the printing process using a scanning system that meets the requirements of Annex D. Ensure that the scanning system can accurately capture the high resolution lightness information of the printed test charts. Ensure that the print is unrotated and aligned with the scanner platen. Colour enhancement and spatial filtration in the scanning system data path shall be disabled. Colour calibration of the scanning system is required to provide CIE Lightness for resolution-score processing (see Annex D). Evaluating multiple print samples permits better statistical estimation of the true resolution-score in the presence of printing system and scanning system noise.

4.3.4 Evaluation process

The process used to evaluate the digital information captured with scans of the printed Contrast–Resolution test charts shall follow the steps specified in Clause 5. Resolution-score processing, Processing shall conform to the requirements specified in Annex E.

5 Resolution-Score processing

5.1 General

The printing system requirements specified in Annex B and C and the scanning system requirements specified in Annex D ensure that the scanned image of a Contrast-Resolution test chart print sample will permit a meaningful analysis. These requirements are essential for analysis and should be checked prior to any further processing.

5.2 Element identification

Supplied with the three versions of the printable Contrast–Resolution test chart, is a reference bitmap image of the Contrast–Resolution test chart, ISO_ConRes20_Reference_1200.tif[6)], representing the output of a perfect printer, scanned by a perfect scanner at 1 200 ppi. This is the ideal case to which 1 200 ppi scans of real prints are compared. This reference bitmap image is utilized in the analysis of any version of the printed Contrast-Resolution test chart.

The exact locations of the circularly symmetric elements in the scanned image of the Contrast–Resolution test chart shall be identified, so that each of these elements may be compared with the corresponding element in the reference bitmap image. Identical fiducial marks are provided in both the printable and reference Contrast-Resolution test charts to aid in locating each region of interest (ROI). Significant errors in identification of the geometric position of an element with respect to its corresponding element in the reference bitmap image will degrade the analysis results.

5.3 Scanning signal interpretation

The scanning system shall deliver a calibrated lightness signal, CIE L*. CIE L* is a well-defined mathematical transformation of the CIE luminance factor, Y and this CIE L* representation of the scanned data is used in all calculations. The means to calibrate a scanning system to deliver this signal can be provided by a suitable linearization of a monochrome scan or is provided by scanner ICC profile creation applications for RGB scans. See Annex D for details. Analysis of the scanned Contrast–Resolution test chart print relies upon the nearly uniform perceptual characteristics of differences in the CIE L* quantity.

5.4 Spatial filtering

A properly dimensioned Gaussian spatial filter is applied to the scanned bitmap image to mimic the spatial response characteristics of the human visual system (HVS) at a standard viewing distance of 40 cm. This filter slightly blurs the image and eliminates structure that a printing system may be able to render that would not be visible to a human observer at this viewing distance. The same spatial filter

6) The corresponding file is provided in the URN: https://standards.iso.org/iso/ts/18621/-31/ed-1/en/.

is used in processing the ideal reference bitmap image. The bitmap of a perfect scan of a perfect print, filtered in this manner, will exactly match the similarly filtered reference bitmap image and represents the detail that a human observer would be capable of seeing at the standard viewing distance of 40 cm. The Gaussian spatial filter appropriate for a viewing distance of 40 cm. is specified in Annex F (normative), Spatial filter.

NOTE A Matlab example of the application of this Gaussian spatial filter to an input image to create afiltered image is: `FiltImage = conv2(double(Image), kernal, 'same')/sum(kernal(:));`

5.5 Normalized 2-D cross-correlation

Following registration of the scanned image with the reference image and spatial filtering to minimize structure in the scanned image that would not be visible to a human observer, each of the elements of the scanned Contrast–Resolution test chart is compared with its corresponding element in the reference bitmap. A normalized two-dimensional cross-correlation calculation is used to provide the measure of similarity between each scanned element and its corresponding reference element. The cross-correlation calculation utilizes a range of horizontal and vertical pixel offset values sufficient to accommodate residual mis-registration between the scanned elements and the corresponding reference elements. The position of the peak value in the cross-correlation coefficient matrix between scanned and reference elements defines the horizontal and vertical pixel offsets that shall be applied to an element of the scanned image bitmap to best overlay the corresponding element in the reference image bitmap. The magnitude of this peak value in the cross-correlation coefficient matrix defines the needed measure of similarity. These cross-correlation peak value coefficients provide measures of similarity between each of the elements in the scanned bitmap of a printed Contrast–Resolution test chart and the reference bitmap representing a perfect scan of a perfect print.

The cross correlation operation is defined in Formula 1:

$$C(\alpha,\beta)=\frac{\sum_{x,y}\left(f(h,v)-\bar{f}\right)\left(g(h-\alpha,v-\beta)-\bar{g}\right)}{\sqrt{\sum_{x,y}\left(f(h,v)-\bar{f}\right)^2\sum_{x,y}\left(g(h-\alpha,v-\beta)-\bar{g}\right)^2}} \tag{1}$$

where

α is the horizontal offset value of the scanned floating-point image used in cross-correlation, in integer pixels;

β is the vertical offset value of the scanned floating-point image used in cross-correlation, in integer pixels;

h is the horizontal coordinate of the floating-point scanned or reference bitmap images, in integer pixels;

v is the vertical coordinate of the floating-point scanned or reference bitmap images, in integer pixels;

$f(h,v)$ is the reference image;

$g(h,v)$ is the scanned image;

$\bar{f}$ is the overall mean value of the reference image;

$\bar{g}$ is the overall mean value of the scanned image.

The peak value of the cross-correlation coefficient matrix, $C(\alpha,\beta)$, is the cross-correlation coefficient value used as a measure of similarity between the scanned bitmap image of a Contrast–Resolution test chart element and the corresponding element of the reference bitmap image that represents a perfect print.

NOTE A Matlab example of the application of normalized 2-D cross-correlation is: `XCoeff = normxcorr2(Sample, Ref);` Where Sample and Ref are the matched scanned and reference Contrast – Resolution test chart ROI elements. XCoeff is the matrix of normalized cross-correlation coefficients [$C(\alpha,\beta)$ of Formula (1)].

5.6 Resolution-score computation

The steps to evaluate the Resolution-score from the elements of a scanned Contrast–Resolution test chart are specified in the following list and in Figures 7 and 8. Measurement follows two parallel paths: (A) involving scanned and reference bitmaps to which a spatial filter simulating human visual capability at a 40 cm. viewing distance has been applied, and (B) involving unfiltered scanned and reference bitmaps that evaluate the capability of the printing system without visual filtering.

1) (Preparation) Ensure that the Contrast–Resolution test chart, ISO_ConRes20, can be properly printed for the evaluation intent with the workflow of the printing system (see Annex B specifications).

2) (Optional preparation) Linearization. See Annex C for details. Linearization is an optional process that maximizes the information content of the Contrast-Resolution test chart through the printing and analysis processes. The tone scale employed by the linearization process is not representative of normal printing operations so linearization should not be employed if the evaluation intent is to assess the resolution capability of a printing system in normal operation. Linearization should be employed if the ultimate resolution capability of a printing system is to be assessed.

3) (Preparation) Identify a qualified scanner for scanning prints of the Contrast–Resolution test chart at the required resolution of 1 200 pixels per inch (ppi) (see Annex D specifications).

4) (Preparation) Calibrate the scanning system for a CIE L* or CIEL*a*b* interpretation using the printing system colorant set (see Annex D specifications).

5) (Preparation) Ensure availability of the 1 200 ppi reference image bitmap of the Contrast–Resolution test chart, ISO_ConRes20_Reference_1200.tif.

6) (Sample) Print samples of the Contrast–Resolution target according to Annex B specifications using the appropriate workflow for the evaluation.

7) (Sample) Scan the printed samples of the Contrast–Resolution test chart according to Annex D specifications.

8) (Sample) Read the uncompressed or lossless compressed bitmap image files of the scanned print samples for analysis.

9) (Analysis) Convert the uncompressed bitmap images of the printed samples to an L* interpretation according to Annex D specifications. This L* representation of a scanned print sample bitmap and the corresponding interpretation of the reference bitmap as an L* representation are the basis for subsequent analysis.

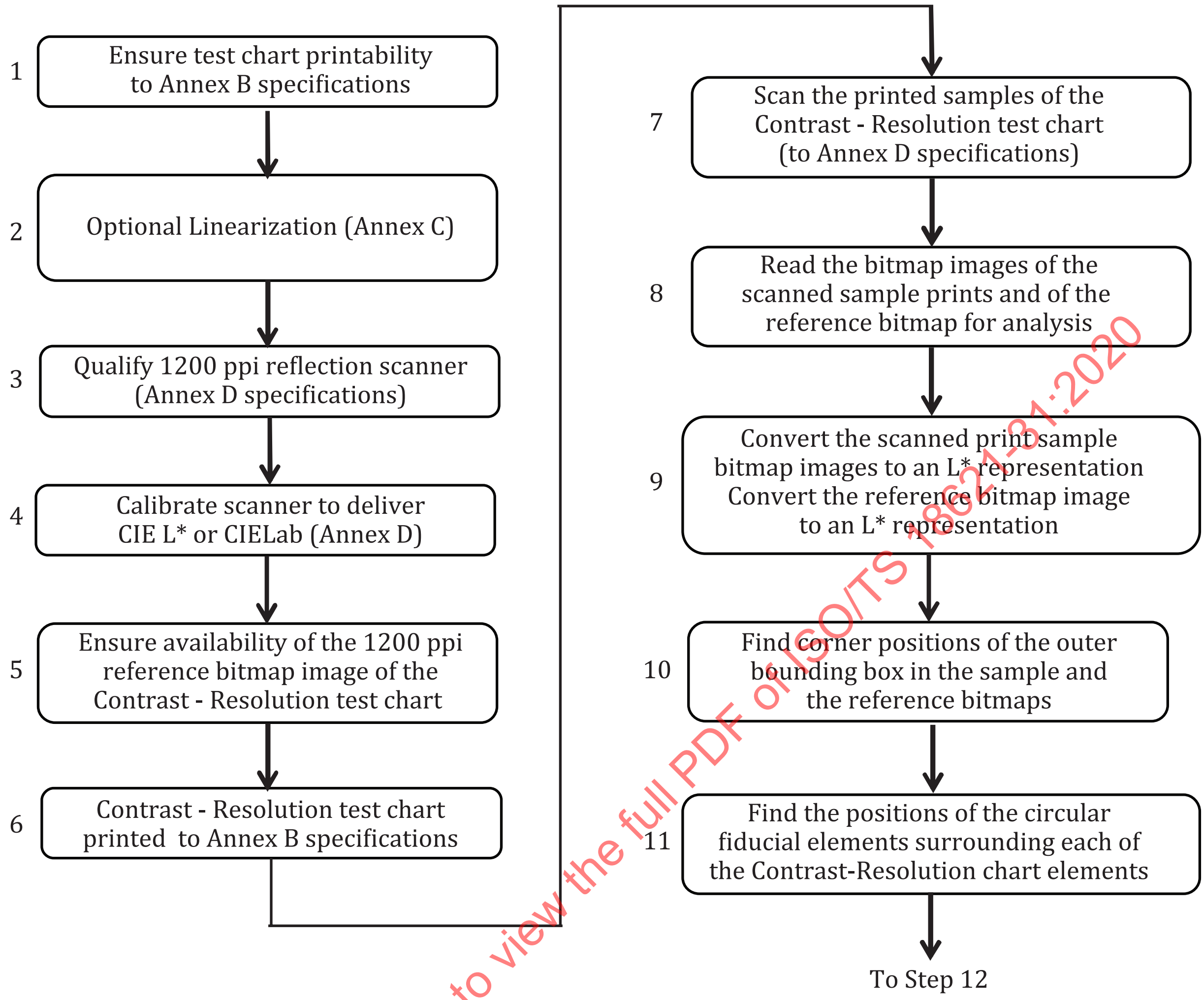


Figure 7 — Flow-chart of Steps 1 through 11 in resolution-score analysis

10) (Analysis) Register the position of each element of the scanned Contrast–Resolution test chart bitmap with the position of the corresponding element in the reference bitmap. This is normally a two-step process: First find the corners of the outer box surrounding the Contrast – Resolution target.

11) (Analysis) Register the position of each element of the scanned Contrast–Resolution test chart bitmap with the position of the corresponding element in the reference bitmap. This is normally a two-step process: Second, determine the locations of the circular fiducial elements at the corners of each element of the Contrast – Resolution target. Use these locations to register the elements.

Analysis A refers to processing of filtered elements.

Analysis B refers to processing of unfiltered elements

12) (Analysis A) The spatial filter specified in 5.4 shall be applied to the L* interpretation of the scanned sample bitmap images and the filtered image set shall be saved in its linear L* interpretation. The spatial filter specified in 5.4 shall be applied to the L* interpretation of the reference bitmap image and the filtered image set shall be saved in its linear L* interpretation.

13) (Analysis A and B) From the registered positions of the test bitmap and the reference bitmap, extract a full size region of interest (ROI) for each element of the unfiltered and the filtered reference image and from the corresponding unfiltered and filtered bitmaps of the scanned sample print for analysis. Include as much as possible of each element but carefully avoid the inclusion of any margins.

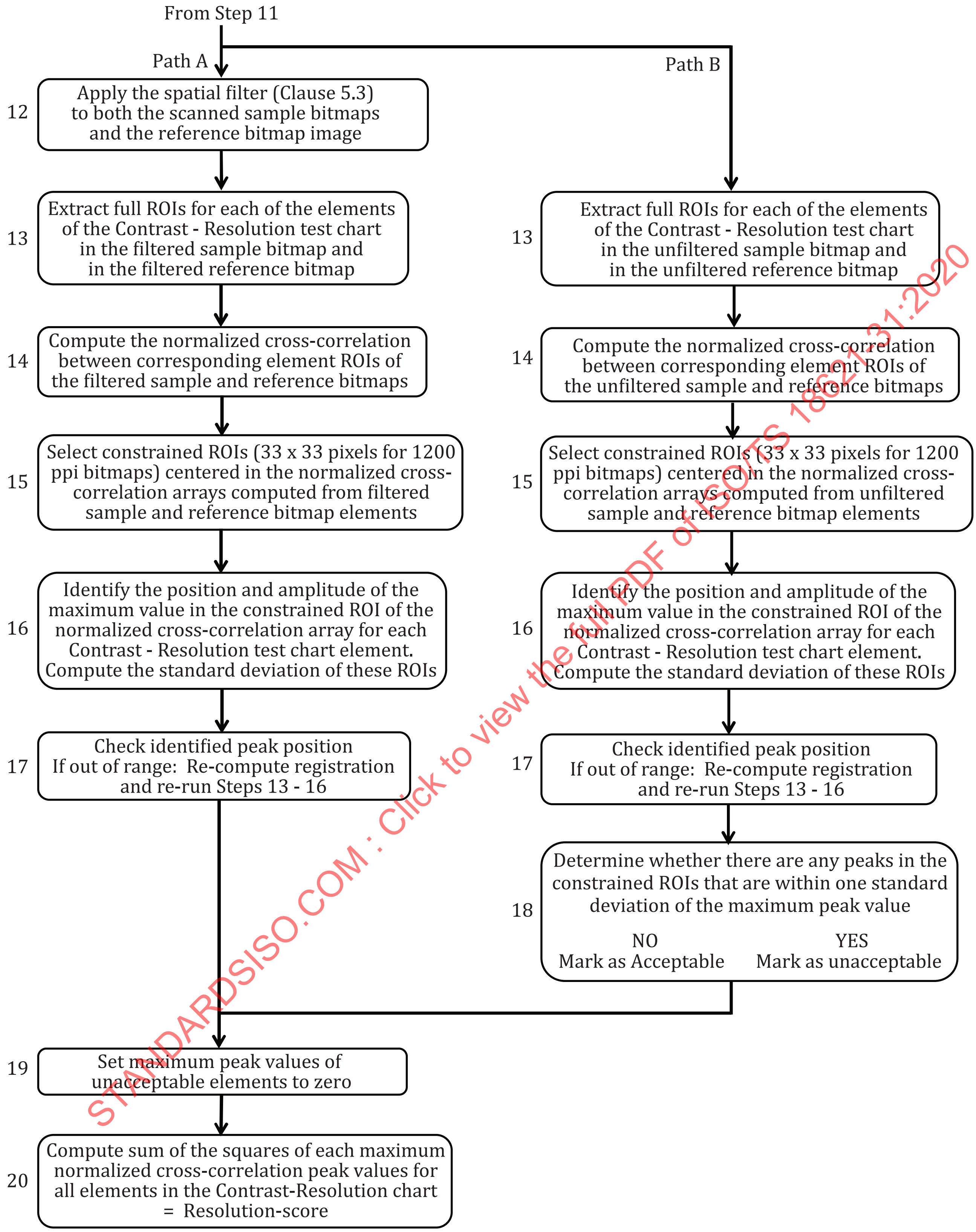


Figure 8 — Flow-chart of steps 12 through 20 of resolution-score analysis

14) (Analysis A and B) For each of these corresponding pairs of full size element ROIs (unfiltered pair and filtered pair), compute the normalized cross-correlation of the ROI element of the scanned bitmap image of the printed test chart sample and the corresponding ROI element of the reference

target bitmap. Pay attention to the requirements of the algorithm that is used – some algorithms require a reference element ROI that is larger and inclusive of the test element ROI size

15) (Analysis A and B) Select a constrained size ROI from the normalized cross-correlation result that is centered at the expected position of the peak in the cross-correlation result and extends horizontally and vertically about this centre to a distance corresponding to two periods of the highest frequency element in the test chart. At 1 200 ppi, this is a 33 x 33 pixel region, used in the analysis of all test chart elements. With careful attention to registration (Step 11), the expected peak position should be near the centre of the normalized cross-correlation array.

    NOTE 1 This size constraint avoids incorrect use of false peaks of the cross-correlation function due to border effects, aliasing or halftone noise. This constraint is particularly useful in the case of low-contrast elements where print noise can be a significant factor.

16) (Analysis A and B) Analyse the coefficient matrix from the normalized cross-correlation of the unfiltered constrained size element ROIs to identify the position and amplitude of the maximum value in the cross-correlation matrix. The maximum value is denoted *Cpeak(i,j)* for each element. Compute the standard deviation of the cross-correlation values within this ROI.

    NOTE 2 Indices *i* and *j* represent pixel rows and columns, respectively, of an element in the test chart.

17) (Analysis A and B) If the position of the maximum peak is at or immediately adjacent to a border of the constrained size ROI, then registration of the test ROI with the reference ROI is not sufficiently precise to provide a valid measurement – a result of improper element registration. In this case, the full size ROIs extracted from the corresponding element of the scanned target bitmap and from the reference bitmap shall be offset from each other to properly center the maximum peak in the cross-correlation result.

    NOTE 3 For lower frequency elements of the Contrast–Resolution test chart, the size of the constrained size ROI can be increased to include two periods of this lower frequency both horizontally and vertically around the expected position of the peak in the cross-correlation result to assist in locating the peak and properly setting the full size ROI offsets to center this peak in the cross-correlation result to within a few pixels. This is normally unnecessary.

    NOTE 4 If, after registration adjustment, the identified peak remains at or adjacent to a border of the constrained-size ROI or if noise dominates the cross-correlation result in the unfiltered constrained-size cross-correlation ROI (see step 18), apply step 19 and continue to step 20.

18) (Analysis A and B) Determine when noise dominates the cross-correlation result in the unfiltered constrained size cross-correlation ROI. This occurs when multiple peaks are found in analysis of the cross-correlation result within one standard deviation (see step 18) of the identified ROI peak value.

19) (Analysis A and B) Set the value of the corresponding local maximum value, *Cpeak(i,j)*, of both the unfiltered and the filtered cross-correlation arrays (a measure of printing system capability) to zero when noise dominates the unfiltered cross-correlation result.

20) (Analysis A) Compute the sum of squares of the filtered normalized cross-correlation local maximum or peak values, *Cpeak(i,j)*, determined in the previous steps for each of the elements (for all rows and columns) of the Contrast–Resolution test chart. This summed value is the Resolution-score value for the printing system under evaluation. This computation is shown in Formula (2).

Formula (2) shows calculation of the resolution-score value for an analysed sample print.

$$Rscore = \sum_{i,j} (Cpeak(i,j))\hat{}2 \qquad (2)$$

where *Cpeak(i,j)* is the local maximum value of the normalized cross-correlation function for row *i* and column *j* of the filtered Contrast–Resolution sample bitmap with the filtered Contrast–Resolution reference bitmap in each constrained size cross-correlation ROI.

These local maximum values range between 0 and 1. There are 100 elements in the Contrast–Resolution test chart, so simple addition of squared values suffices. Resolution-score values range between 0 (no resolution capability) and 100 (perfect print).

6 Reporting

Table 2 specifies the documentation required to define the context of a report of a resolution-score evaluation. The printing system shall be set up according to the requirements of Annex B and Annex C to deliver sample prints of the test chart specified in Annex A with image structure consistent with the desired evaluation intent. The scanning system shall be set up and calibrated, as specified in Annex D, in a manner consistent with digitization of the sample prints for Resolution-score evaluation according to the desired evaluation intent.

Table 2 — Report structure

Test chart used:	Filename of the Contrast–Resolution test chart utilized.
Printing system evaluated:	Manufacturer and Model.
Printing system addressibility:	Printing system addressability used in printing test chart samples, e.g. 1 200 ppi.
Substrate surface:	Substrate surface characteristics (optional substrate manufacturer and name).
Evaluation intent:	Name of the evaluation intent utilized, as listed in Table 1.
Observed image structure:	Single colorant or multiple process colours.
Colour management:	Colour management settings and ICC profiles employed,
	Method utilized or N/A if colour management not utilized.
Linearization method:	Method utilized ('CIELab' if Lab target utilized or N/A if linearization not utilized)
Linearization measurement:	Measurement method ('Inherent' if Lab target utilized or N/A if linearization not utilized).
Additional documentation:	Documentation of settings that may affect printing system resolution capability.
Scanning system utilized:	Scanner manufacturer and Model.
Scanning system addressability:	1 200 ppi
Additional documentation:	Documentation of scanning system settings that may affect scanning system capability
Scanner calibration:	Single-channel (specify which channel and CIE L* calibration method) or ICC profile for CIELab colour calibration of RGB scans.
Scanner MTF @ 12 cy/mm:	Evaluated value from scanner qualification.
Resolution-score value:	Evaluated value (averaged over measurements of multiple print samples).
Number of prints evaluated:	Number of print samples utilized in the measurement.

The first items in the report documents the manufacturer and model of the printing system being evaluated as well as the name of the test chart utilized in the evaluation.

The "Printing system addressability" item documents the addressability of the printing system workflow used for printing samples of the Contrast–Resolution test chart. The "Substrate surface" item documents the surface structure of the substrate – which can significantly affect the results of the evaluation.

The printing procedure and printing system workflow used in printing the Contrast–Resolution test chart are documented by the "Evaluation intent" item as specified in Annex B or Annex C. The image structure observed under magnification in the printed and analyzed test charts is documented in the "Observed image structure" item. The "Colour management" item shall record how the printing system colour interpretation of the Contrast–Resolution test chart was set up for the desired evaluation intent. The printing system "Linearization method" item documents the method used to obtain the tone scale utilized in the evaluation or N/A if linearization is not employed. The "Linearization measurement" item documents the patch measurement process used for obtaining data for the linearization method or N/A if linearization is not employed. Any additional documentation required to reproduce the printing system state shall be included in the "Additional documentation" item.

The Scanner utilized for Resolution-score evaluation shall conform to the scanning system requirements specified in Annex D. The scanning system set up and scanner calibration method shall be matched with the type of sample prints employed (single colorant or process colour) and with the desired evaluation intent.

The required scanning system addressability is 1 200 ppi (see Annex A and Annex D).

The scanning system shall be set up as specified in Annex D. Careful attention to the details specified in Annex D is essential for obtaining usable scan data. Any qualms in the setup of a scanner to the specifications of Annex D should be documented in the report.

For single colorant evaluation, used to provide an estimate of the inherent capability of a printing system, the scanner calibration method shall utilize a single sensor array of the scanner (usually the green channel) thus avoiding any degradation due to mis-registration between the scanning system color sensors). Single colorant evaluation shall utilize a simple scanner calibration that is linear in CIE L* based upon the single colour sensor array most responsive to the print colorant, as specified in Annex D. These steps avoid any mis-registration in printing or between scanning system colour sensors. For process colour evaluation, the Contrast–Resolution test chart shall be scanned using scanner calibration software that delivers CIE L*a*b* scan files according to the procedure defined in Annex D. The "Scanner calibration" item documents the scanner setup utilized for scanning print samples of the appropriate Contrast–Resolution test chart.

The "Scanner MTF @ 12 cy/mm" item reports the scanner MTF value obtained in qualifying the scanner for use with this document as specified in Annex D and shall meet or exceed an MTF level of 0,2 at 12 cycles per millimetre.

The resolution score shall be reported as a value between 0,0 and 100,0, rounded to one decimal place and may be obtained by averaging the evaluations of a number of printed Contrast–Resolution test chart print samples. The process used to evaluate Resolution score values shall be in compliance with the process specified in 5.6. The number of prints evaluated records the number of print samples utilized in the statistical estimation of the reported resolution-score value.

The "Additional documentation" field is provided to document any workflow and evaluation operations that can affect the measurement of perceived resolution such as intentional inclusion of image enhancement operations normally part of a production workflow or a noticeable level of mis-registration in the sample prints.

Annex A
(normative)

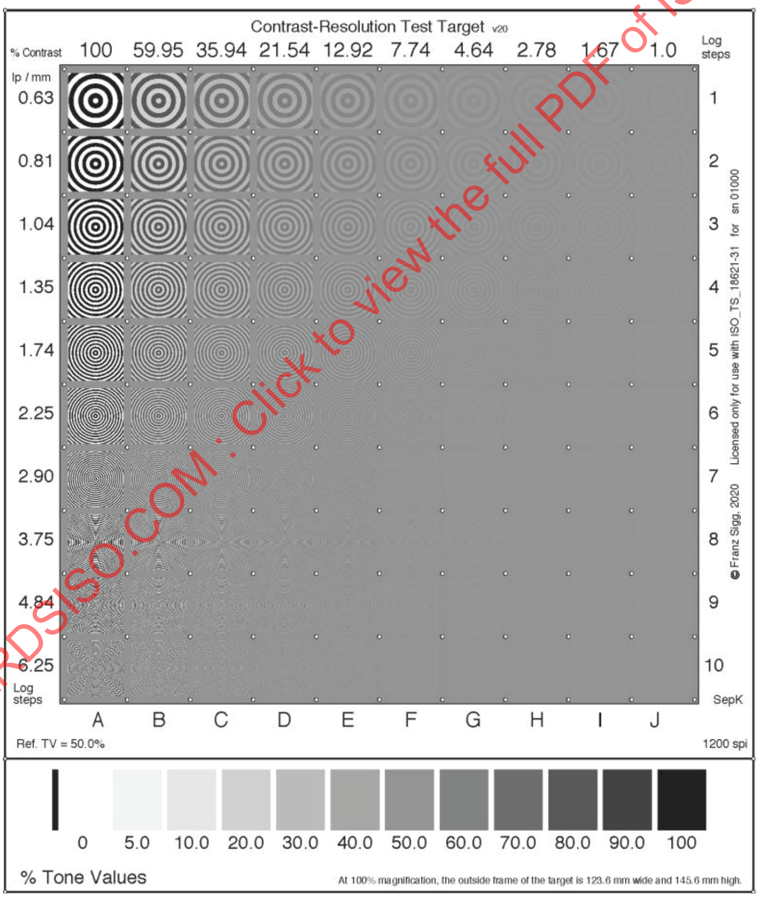
Test chart and reference files — Availability

The Contrast–Resolution test chart required for the evaluation of printer resolution as specified in this document is provided in three different printable versions in PDF format. These three PDF format files can be found in https://standards.iso.org/iso/ts/18621/-31/ed-1/en/:

1) ISO_ConRes20_SepK.pdf which is intended for single colorant resolution capability evaluation.

2) ISO_ConRes20_sRGB.pdf which is intended for process colour resolution capability evaluation. Information in the ISO_ConRes20_sRGB.pdf test chart is encoded using a standardized sRGB colour space. No additional sRGB profile need be embedded in the PDF file.

3) ISO_ConRes20_Lab.pdf which is intended for resolution capability evaluation, and inherently uses the optional linearization process defined in Annex C.



NOTE From (ISO_ConRes20_sepK.pdf).

Figure A.1 — Contrast–Resolution test chart

The reference bitmap file, ISO_ConRes20_Reference_1200.tif, required for the evaluation of printer resolution capability as specified in this document through comparison with the scanned print of either printable version of the test chart, can be found in https://standards.iso.org/iso/ts/18621/-31/ed-1/en/.

This lossless, LZW-compressed, TIFF format bitmap file is a perfect reproduction of the Contrast–Resolution test chart with no visual filter applied (as specified in 5.3). This 8-bit bitmap file is encoded with 0 – 255 corresponding to 0 – 100 L* values. This mimics the processing flow of the scan of a printed test page, but printed with a 'perfect' printer and scanned with a 'perfect' 1 200 ppi scanner, so the scanned test page elements and the reference elements are directly comparable.

All of the digital files required for the use of this document are available from ISO at the web site: https://standards.iso.org/iso/ts/18621/-31/ed-1/en/. The Test Charts.zip file contains the three PDF format Contrast–Resolution test charts. The reference bitmap file, ISO_ConRes20_Reference_1200.tif, is contained in the Conformance.zip file along with additional files required for conformance evaluation (see Annex E).

A rendition of the SepK version of the Contrast–Resolution test chart is shown in Figure A.1 (aliasing may be present in the high frequency elements of this rendition due to reproduction constraints). The 100 individual test elements are each nominally 9 mm. square with an approximately 1,35 mm. margin between each patch. A twelve element tone-reproduction step tablet is provided below the array of circular Contrast–Resolution elements to provide a check on the printing system tone scale and for use in the linearization process defined in Annex C.

The small circular fiducial marks that surround each test element are centered in the margin areas. An inner rectangular border is written around the outside of the 10 × 10 array of test elements and the 11 × 11 array of fiducial marks. An outer rectangular border is written one patch size outside the inner rectangular border and surrounding the tone scale step tablet below the array of test elements. Determination of the location of the outer boundary enables simple prediction of the inner fiducial mark positions. Determination of the centroids of the fiducial mark positions permits a precise location of an ROI consisting of a test element with no included margin. In practice, a 'full-size' test element ROI will be slightly smaller than its maximum size to allow for slight rotations of printed samples when placed on a scanner bed for scanning. Table A.1 lists the expected positions of the four corners of the outer boundary surrounding the array of the Contrast–Resolution elements and the expected positions of the four corners of the boundary surrounding the tone scale step tablet test chart in pixels at 1 200 ppi.

Table A.1 — Expected corner positions of the fiducials in the outer bounding rectangle

a) Element array

	Horz.	Vert.
ULC	0	0
URC	5 816	0
LRC	5 816	5 816
LLC	0	5 816

b) Step tablet

	Horz.	Vert.
ULC	0	5 816
URC	5 816	5 816
LRC	5 816	6 855
LLC	0	6 855

The expected positions of the circular fiducial marks that surround each test element are predicted based upon the corner positions of the outer boundary of the test chart and the expected horizontal axis and vertical axis offsets of the rectangular grid on which the circular fiducial marks are written. Table A.2 lists these expected offsets from the ULC of the outer boundary in pixels at 1 200 ppi.

The 11 x 11 grid of circular fiducial positions is created from combinations of the 11 horizontal axis offsets and the 11 vertical axis offsets. The outer edges of the individual Contrast–Resolution test chart elements are half the margin size, about 32 pixels at 1 200 ppi, within the rectangle connecting adjacent fiducial positions.

The maximum size of an extracted Contrast–Resolution test chart element is then about 426 × 426 pixels. Allowing some additional margin to accommodate misalignment of the test chart on the scanner platen, a reasonable individual element ROI is 410 × 410 pixels at 1 200 ppi (accommodating a 2° skew angle).

Table A.2 — Expected offsets of circular fiducials from ULC of outer boundary

	Horz.	Vert.
ULC	458	458
2	948	948
3	1 438	1 438
4	1 928	1 928
5	2 418	2 418
6	2 908	2 908
7	3 398	3 398
8	3 888	3 888
9	4 378	4 378
10	4 868	4 868
LLC	5 358	5 358

The three versions of the printable Contrast–Resolution test chart are provided in PDF format. The underlying code that implements the structure of the test charts are vector specifications that are largely independent of the addressability of the printing system being evaluated. See Annex B or Annex C for the definition of printing processes that conform to the specifications of this document.

A web site at www.conres.io has been made available to provide support for the use and analysis of the Contrast–Resolution test chart in the assessment of printing system resolution capability. This site provides:

— Additional information about the use and interpretation of the Contrast–Resolution test chart.

— Technical assistance to enable adaptation of the measurement process described in this document to special printing circumstances.

— A free service for the analysis of scanned bitmaps of printed Contrast–Resolution test charts according to the analysis procedure defined in this document:

  — Share a scanned bitmap of a printed Contrast–Resolution test chart via a file-sharing service, and

  — Receive back a detailed analysis of the resolution capability of that printing system.

— An issue management mechanism to provide user feedback regarding the usefulness of the measurement method defined in this document. User feedback is essential for the refinement of this measurement method.

  — Are there areas in this evaluation of printing system contrast and resolution capability that do not match your perceived impression of the evaluated printing system's resolution capabilities?

  — In what manner does your perception of printing system resolution capability differ from that reported by this measurement method?

A small set of PDF RIPs do not strictly follow Adobe® Red Book Postscript specifications and can introduce geometric errors when interpreting the concentric circle patterns of the Contrast–Resolution test charts. These interpretation errors usually show as lighter or darker circular rings, primarily in the high spatial frequency regions of the Contrast–Resolution test chart elements. Each of the 100 circular pattern elements in the test chart should be uniform and the visual weight of rows and columns of a printed test chart should be uniform. Use the technical assistance available at www.conres.io to help us resolve these issues.

The www.conres.io web site is provided to assist in the refinement of this measurement method.

Annex B
(normative)

Printing process and data path requirements

B.1 Printing system requirements

The printing system under evaluation shall be stable, providing the same measured print tone-scale for a defined set of input values. Without stability, calibration, linearization and reproducible measurement are all meaningless. Print-to-print tone-scale variation should be repeatable within ±1 ΔE.

Both objective measurement and subjective evaluation of Contrast–Resolution test charts printed with process colorants are only slightly affected by the low levels of colorant mis-registration present in modern, well maintained printing systems. The level of colorant mis-registration in printed test charts should be verified to be low when utilizing the procedure specified in this document with process color printing.

The clearest measure of the *inherent resolution capability* of a printing system will be provided through evaluation of a Contrast–Resolution test chart printed with a single process colorant where any measurement degradation due to process colour mis-registration is absent – the perceived resolution that a printing system delivers when reproducing black text. The clearest measure of the *practical resolution capability* of a printing system is best provided through evaluation of a Contrast–Resolution test chart printed with full process colorants – the perceived resolution that a printing system delivers when reproducing colour images.

The optional Linearization process (see Annex C) maximizes the information content of the test chart through the printing process and the analysis of the resolution capability of a printing system but utilizes a tone-scale that is not representative of normal printing operations. A third version of the Contrast–Resolution test chart, ISO_ConRes20_Lab.pdf, is provided for linearized evaluation of process colour resolution capability.

In all cases, the printing procedure shall maintain 100% of the original size of the Contrast–Resolution test chart.

Avoid any sharpening or enhancement operations that are not part of the intended printing system workflow to be evaluated. If enhancement operations are to be evaluated, the settings of these operations shall be documented in the "Additional documentation" field of the test report.

RIPs generally accept a PDF format file directly, but there is a remote possibility that the vector code within the PDF versions of the Contrast–Resolution test chart can be misinterpreted by a printing system RIP. If a PDF file is mis-interpreted or cannot be accepted by a printing system RIP, the reference TIFF image may be submitted instead, in the appropriate representation for the evaluation intent and as long as the full 1 200 ppi bitmap addressability is maintained throughout the workflow.

B.2 Printing process

B.2.1 General

The contrast-resolution test target samples the capability of a printing system to resolve spatial detail with a two-dimensional matrix organization of test elements. Rows are at discrete logarithmically spaced values of resolution and columns are at discrete logarithmically spaced values of contrast.

Local variations in the printing system tone scale can adversely affect the measurement of perceived resolution. Linearization of the printing system to provide equal CIE Lightness steps for equal printing specification steps provides a mechanism that maximizes the information content of the test chart through the printing process and the analysis of the resolution capability of a printing system but utilizes a tone-scale that is not representative of normal printing operations. See Annex C for details about linearized evaluation of printing system resolution capability. If the linearization process specified in Annex C is utilized, the process used for linearization shall be specified in the linearization items of the report, otherwise these item shall be marked N/A (for not applicable). See Table 1.

Six different processes have been defined to address different evaluation intents in the assessment of printing system resolution capability. The two evaluation intents involving linearization, primarily useful in engineering evaluation, are discussed in Annex C, the four evaluation intents most useful for the assessment of printing system resolution capability in normal printing operations are discussed here in Annex B.

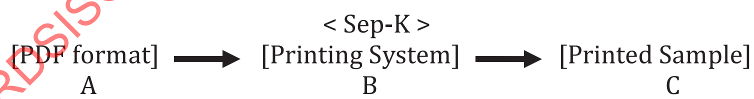
B.2.2 Evaluation of device-specific resolution capability (Setup 1)

This printing process is valid only for evaluation and comparison of different states of a single printing system and may be useful in engineering evaluation. A single conforming reflection scanner is customarily used for evaluation consistency. The Contrast–Resolution test chart is supplied directly to a printing system that is set up in a particular condition. Documentation of the setup of the printing system to this condition is required in the test report to enable subsequent return to this condition for further evaluation. Device-specific evaluation may use any version of the test chart.

B.2.3 Evaluation of single colorant inherent resolution capability (Setup 2)

To avoid resolution degradation inherent in even low levels of mis-registration of multiple colorants, this evaluation setup employs printing with only a single process colorant, typically the black separation. The single colorant version of the Contrast–Resolution test chart, ISO_ConRes20_SepK.pdf, defines spatial information in a device-dependent separation-black colour space. In most printing systems, information in this colour space completely bypasses the printing system colour management system and specifies the amount of the single printing system black colorant to be used in printing a feature. If this information does not bypass the printer's colour management system, some colorant other than the intended colorant may be printed in some areas of the test chart. Print samples for evaluation shall be printed with a single colorant. The user of this document shall take careful note of the image structure in printed Contrast–Resolution test charts to verify that all elements are printed with a single colorant (see NOTE). Please consult the Contrast–Resolution test chart support site at www.conres.io for assistance in specialized applications.

The single colorant printing process for the evaluation of inherent resolution capability is illustrated in Figure B.1.



Key

A The specified single colorant Contrast–Resolution test chart, ISO_ConRes20_SepK.pdf.

B The printing system interprets the Separation-K values and produces sample prints using a single printing system colorant.

C The hardcopy printed samples using a single printing system colorant are produced in conformance with Annex B.

NOTE If additional colorants are printed, the use of a black preserving DeviceLink profile, usually K=K, or paying special attention to workflow specific settings (e.g. disabling colour management) can provide the required single colorant printing intent.

Figure B.1 — Single colorant Contrast–Resolution test chart printing procedure

B.2.4 Evaluation of process colour practical resolution capability (Setup 3)

The sRGB encoding of the Contrast–Resolution test chart, ISO_ConRes20_sRGB.pdf shall be used for the evaluation of practical colour resolution capability. The sRGB encoding of this test chart aids in the required interpretation of the neutral tints of the test chart as process colours by the RIP colour management system. This permits straightforward evaluation of any colour managed workflow and rendering intent that is relevant for a particular printing operation. For accuracy, a custom ICC profile that is built from the measured characteristics of the printing system being evaluated shall be utilized for the output transform of the colour management system. Print samples for evaluation shall be printed with multiple process colorants (see NOTE below). The user of this document shall take careful note of the image structure in printed Contrast–Resolution test charts to verify that the test charts are printed using multiple process colorants.

To enable comparison of the practical resolution capability of different printing systems each evaluated printing system should be individually set up to as similar as possible tone-reproduction aims. Figure B.2 illustrates the printing procedure for measurement of Resolution-score, as specified in 5.6, with the intent of evaluating the practical resolution capability of a commercial print operation.

<sRGB>

[PDF format] → [Printing System] → [Printed Sample]

A B C

Key

A The specified process colour Contrast–Resolution test chart, ISO_ConRes20_sRGB.pdf.

B The printing system colour management system interprets the sRGB values and provides process colorant amounts for printing a process colour sample print of the Contrast–Resolution test chart using a recent custom printing system output ICC profile.

C The hardcopy printed samples are produced in conformance with Annex B using process colorants.

Figure B.2 — Process colour Contrast–Resolution test chart printing procedure

The sRGB encoded version of the Contrast–Resolution test chart is submitted directly to the printing system to obtain sample prints. A stable and reproducible context for resolution score evaluation is provided by color managed implementation of normal printing system operation. For accuracy, a custom ICC profile that is built from the measured characteristics of the printing system being evaluated shall be utilized as the output transform of the colour management system.

NOTE Special attention to colour management system settings should be taken to avoid interpretation of equal RGB values (R=G=B) as a single process black colorant (unless evaluation of single colorant inherent resolution capability is actually desired).

B.2.5 Evaluation of standardized process colour practical resolution capability (Setup 4)

Standardized process colour evaluation of the practical resolution capability of a printing system (setup 4) involves a small change in the workflow specified in B.2.4. As illustrated in Figure B.3, the output colour interpretation of the printing system shall be set up to simulate the colour reproduction aims of a commercially important printing application. This aim may be achieved in multiple ways. See NOTE for examples. This simulation aim ensures the closest possible reproduction of the colour aims of the standardized printing application using the colour reproduction capabilities of the printing system being evaluated. The sRGB encoding of the Contrast–Resolution test chart is utilized by the RIP colour management system to provide an interpretation of the neutral tints of the test chart as process colours. For accuracy, a custom ICC profile that is built from the measured characteristics of the printing system being evaluated shall be utilized as the output transform of the colour management system. Print samples for evaluation shall be printed with multiple process colorants (see NOTE below). The user of this document shall take careful note of the image structure in printed Contrast–Resolution test charts to verify that the test charts are printed using multiple process colorants.

(Printing system colour management, sRGB input)
[PDF format] → [Simulation] → [Printing System] → [Printed Sample]
A B C D

Key

A The specified process colour Contrast–Resolution test chart, ISO_ConRes20_sRGB.pdf.

B As part of the printing system colour management, provide simulation of a commercially important printing application from sRGB input.

C The printing system colour management system interprets the simulated test chart specifications to provide process colorant amounts (using a custom ICC profile that is built from the measured characteristics of the printing system being evaluated) for printing process colour sample prints of the Contrast–Resolution test chart.

D The hardcopy printed samples are produced in conformance with Annex B using process colorants.

Figure B.3 — Standardized process colour Contrast–Resolution test chart printing procedure

To simulate a standard commercial offset printing application on coated stock, an ISOcoated-v2 ICC profile available from www.eci.org can be utilized in combination with the custom ICC profile for the printing system being evaluated. For simulation of other printing applications, the standardized ICC profile appropriate for simulation of that printing application is substituted. To evaluate a news print application, the ISOnewspaper26v4.icc profile available from www.eci.org or from www.ifra.com can be used. To evaluate gravure printing, the PSR_papertyp_V2_M1.icc profile, available from www.eci.org can be used.

NOTE One method of achieving the simulation of a commercially important printing application is to utilize a device link profile constructed from the standardized ICC profile of a commercially important printing application and a custom ICC profile built from the measured characteristics of the printing system being evaluated. Another method to achieve the same aim would be to send the test chart data through a round-trip of the ICC profile of the printing application to be simulated: first through the PCS to device table of the profile of the device to be simulated, using the current rendering intent, and then back to PCS using the colorimetric intent of that same profile's device to PCS table. The resulting data would then be passed through the PCS to device colorimetric table of the actual printer profile. Depending on whether simulation of the printing system application paper colorimetry is desired or not, the colorimetric intents would be absolute or relative.

Annex C
(normative)

Linearization

C.1 Linearization process

Non-linearities in the printing system tone-scale of a production workflow may result in some columns (contrast) of the Contrast–Resolution test chart printing well while other columns may be compromised resulting in an overall degradation of measured resolution capability.

The aim of the linearization process is to compensate for any printing system tone-scale non-linearities and provide the greatest possible amount of spatial information to the surrogate of a human observer provided in the analysis process for resolution capability evaluation. This translates to matching the sample print tone scale provided by the printing system to the characteristics of human perception as closely as possible. This aim is approached by utilizing the nearly uniform L*a*b* scale of colour difference perception defined by the CIE. Measurement of CIE L*a*b* values are specified in ISO 13655.

The method used for linearization shall be specified in the "Linearization method" item of the report and the process used for obtaining measurement data shall be specified in the "Linearization measurement" item of the report, see Clause 6.

Linearization is completely unnecessary in device-specific evaluation of resolution capability (see B.2.2) and linearization of standardized process colour resolution capability defeats the purpose of that evaluation intent (see B.2.5).

C.2 Linearized single colorant resolution capability (setup 5)

Linearization of the printing system specifications encoded in the ISO_ConRes20_SepK.pdf test chart may be accomplished at several points in the printing system workflow and the process used to provide the linearization aim tone reproduction characteristic will vary depending on workflow specifics. Many printing systems have a built-in linearization system (sometimes called calibration) that may be used to provide the linearized printing system aim, often provided by a one-dimensional look-up-table (LUT).

The aim tone reproduction characteristic for linearized single colorant inherent resolution capability is to provide a linear relationship between printing specification (%dot) and measured Lightness (L*) according to the appropriate measurement process specified in ISO 13655 (M0, M1 or M2). The maximum measured Lightness, L^*_{max}, corresponds to printed areas of zero percent-dot (media white) and the minimum measured Lightness, L^*_{min}, corresponds to regions printed with maximum colorant, 100 percent-dot. The aim tone reproduction relationship between measured Lightness (L*) and printing specification (%dot) provided in the ISO_ConRes20_SepK.pdf test chart is given by Formula (C.1).

$$L^*_{aim} = L^*_{min} + \left(\left(L^*_{max} - L^*_{min} \right) x \ (100 - \%dot)/100 \right) \tag{C.1}$$

Linear regression of the measured tone reproduction characteristic, L^*_{meas}, of a step tablet of at least 11 steps (between 0 and 100 %dot) plotted against the aim tone reproduction characteristic, L^*_{aim}, should be a linear characteristic with a standard fit error (rms of fit error from aim) of less than 1 % of the measured range.

If the spot colour tone value (SCTV) scale specified by ISO 20654 is more familiar, SCTV value may be substituted for L* in Formula C.1 and in the linear regression fit to achieve the same aim tone reproduction characteristic.

C.3 Linearized process colour resolution capability (setup 6)

Linearized evaluation of process colour resolution capability is very simply provided through use of the third version of the Contrast–Resolution test chart provided with this document, ISO_ConRes20_Lab.pdf. In this version, printing specifications are provided as CIE-based, neutral-scale CIE L*a*b* values. Submission of this test chart to a colour managed printing system with the input interpretation set to relative colorimetric and the output transform of the colour management system utilizing a custom ICC profile built from the measured characteristics of the printing system being evaluated will provide prints with the desired linearization aim tone-reproduction characteristic for evaluation. The "Linearization method" item in the report (see Clause 6) should indicate "CIE L*a*b*" input and the "Linearization measurement" item in the report (see Clause 6) should indicate that linearization is "Inherent" in the CIELab encoding of the Contrast–Resolution test chart.

Annex D
(normative)

Scanner conformance requirements

D.1 General

The measurement method utilized in this document to evaluate the perceived resolution of a printing system employs a reflection scanner as an analytic measurement device. Measurements provide an accurate assessment of printer resolution characteristics only if the scanner capabilities are sufficiently high that the scanner itself does not limit the assessment and if the scanner control application is configured to deliver pristine imagery. This Annex specifies the conditions that shall be met by a reflection scanner and its scanner control application to qualify a scanner as a usable measurement device for use with this Technical Specification.

Six characteristics of a reflection scanner system shall be evaluated in order to qualify a reflection scanner for use with this document. These characteristics are:

— Interpolation effects in the sensor filter array of the scanner;

— The tone-scale or opto-electronic conversion function (OECF) characteristics of the scanner;

— The scan uniformity over the tone scale and stability over time;

— The MTF characteristics and usable addressability of the scanner;

— Scanner MTF uniformity over the area required for assessment; and

— The capability of the scanning system to be calibrated to provide an accurate measure of CIE L*, which is used in all of the calculations to evaluate perceived resolution.

Several other characteristics of a reflection scanner can affect the measurement process specified in this document, but are generally sufficiently well controlled in commercially available reflection scanners to be of small concern in application to printing system resolution characterization using most types of substrates. These characteristics are:

— The scanner dynamic range capability (minimum to maximum density, free of saturation effects). ISO 21550 specifies a measure of this property. A qualified scanner should cover a dynamic range greater than that of the printing system being evaluated.

— The illumination geometry of the scanner. If the Contrast–Resolution test chart has been printed on a structured substrate, multi-directional illumination is required in the scanner optics to minimize shadowing.

— The flare or integrating cavity effects of the scanner.

— The geometric distortion of the scanner.

D.2 Scanner sensor array requirement

The filter array of the sensor in a qualified scanner shall not compromise the spatial resolution of scanned data. Scanners utilizing independent, full resolution sensor arrays, one for each colour can qualify for use with the measurement methods specified in this document. Scanners utilizing a single linear sensor with an alternating colour filter array will compromise the spatial resolution of scanned data and shall not be used since spatial information is interpolated. Full fast-scan resolution is required for scanner conformance.

A reflection scanner qualified for use with the measurement methods specified in this document shall have a sufficiently large field of view to scan an entire A4 or Letter-size test page without re-positioning the test page. A qualified reflection scanner shall have a scanning resolution of 1 200 ppi over this area.

For comparison between measurements made with different scanning systems, the scanners employed should have similar characteristics: addressability, illumination, tone scale, spatial response and spectral response.

D.3 Scanner OECF characteristics

D.3.1 General

The scanner spatial uniformity and temporal stability shall permit calibration of the scanner to provide a monotonic OECF characteristic with at least 256 steps that does not saturate at either end of its range for the reflection characteristics of the printed test charts utilized in this document. This corresponds to at least an 8-bit scanning system data path and provides headroom for OECF calibration. The calibrated OECF characteristic is for CIE L* measurement.

NOTE The step tablet used for creation of an OECF characteristic shall have twelve or more steps with an optical density range that completely includes the printing system density range.

D.3.2 Method for evaluating the scanner OECF characteristic

A fully populated look-up-table (LUT) that captures the calibration of the scanner is required by the assessment methods specified in this document. Calibration of a reflection scanner in the form of this required LUT shall be done in accordance with the procedure defined in ISO 14524. The standard error of the scanner calibration shall be less than 1% of the required scanner dynamic range (< 1 CIE L* unit) to provide a sufficiently stable OECF calibration.

The details of the scanner calibration methods required for single colorant and for process colour evaluation of Resolution score values are specified in D.4.

D.3.3 Required scanner OECF stability

Scanner OECF repeatability shall be evaluated by performing sixteen consecutive scans of the same OECF calibration test element (e.g. ISO 16067-1 or equivalent test page) at a scanning resolution of 1 200 pixels per inch. The OECF characteristic for each of these sixteen consecutive scans shall be evaluated. The deviation of the OECF characteristic for any individual scan from the averaged OECF characteristic of the sixteen scans shall remain within ±1 CIE L* unit over the entire tone scale.

NOTE The surface texture of an OECF calibration test page can introduce noise in OECF calibration depending on the scanner illumination geometry. Minimum texture or a gloss surface is preferred.

D.4 Scanner MTF characteristic

D.4.1 General

The MTF characteristic of a scanning system describes that scanning system's capability to resolve fine spatial detail – a characteristic central to the evaluation of a printing system's perceived resolution and to the evaluation of a printing system's Resolution-score.

D.4.2 Required scanner MTF characteristic

The detail carrying capability of a scanner shall be evaluated in accordance with the procedure defined in ISO 16067-1 Photography: Spatial resolution measurements of electronic scanners for photographic images. The Matlab function sfrmat3[8] or the MTFmapper[9] application implements this procedure.

To be qualified to evaluate the resolution capability characteristic of a printing system, the scanning system shall provide an MTF characteristic that maintains a modulation level of at least 0,2 up through a spatial frequency of 12 cy/mm.

D.4.3 Required target placement

The printed Contrast–Resolution test chart shall be placed in the central third of the scanner platen along both the slow-scan and fast-scan axes of the scanner to avoid potentially significant variations in the scanner MTF characteristic.

To be qualified to evaluate the resolution capability characteristic of a printing system, the scanning system shall maintain its MTF capability at 12 cy/mm within a total range of 0,035 (out of 1) over the platen area used for evaluation.

If the MTF characteristics of a qualified scanner have been measured to be effectively constant over a larger fraction of the platen along an axis (e.g. slow-scan), then measurements may be made over the fraction of the platen where the MTF shift at 12 cy/mm is within a total range of 0,035 (out of 1).

D.5 Methods for scanner signal calibration

D.5.1 General

The calibration method utilized for reflection scanner measurement of a printed Contrast–Resolution test chart is specific to the workflow path used to print the sample for measurement.

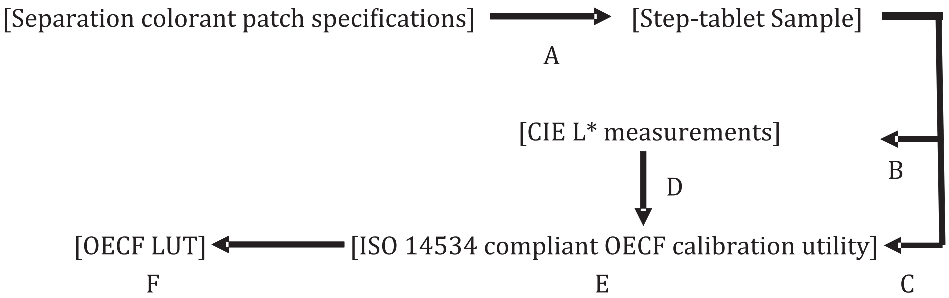
1) For the single colorant printing workflow specified in Figure D.1, a single scanner channel (e.g. green channel) CIE Lightness calibration, defined in D.5.3 shall be used.

2) For the process colour printing workflow specified in Figurer D.2, colorimetric calibration of the reflection scanner to deliver accurate CIELab measurements, as defined in D.5.3 shall be used.

D.5.2 Scanner signal calibration for a single colorant printing system evaluation.

In single colorant printing system evaluation, printed samples of the Contrast–Resolution test chart are produced by a press system using a single process colorant. Calibration of the scanner OECF characteristic according to the process defined in ISO 14524 shall use a scan of a printed step tablet encompassing the printing system density range in at least twelve steps, printed using the process colorant or colorants used in printing the Contrast–Resolution test chart, and measured according to ISO 5 (all parts) densitometry, colorimetry or spectrophotometry to evaluate the CIE Lightness (CIE L*) of the step tablet patches. The process conditions for production of the single colorant step tablet should be slightly over-driven to provide a colorant density range slightly greater than that normally provided by the press to ensure that calibration limits and subsequent measurement clipping are never encountered during evaluation. The steps in this calibration process are defined in Figure D.1.

For black colorant evaluation, a commercially available step tablet with at least twelve steps encompassing slightly more than the density range of the printing system to be evaluated may be used. Densitometric, colorimetric or spectrophotometric measurement of the commercially available step tablet to evaluate CIE Lightness (CIE L*) that is utilized in the calibration is still required. Steps (B), (C), (D), (E) and (F) of Figure D.1 apply.



The steps in the single colorant scanner calibration process are:

A Obtain a step tablet of sufficient density range and steps (at least 12) by single colorant printing or from a commercial source.

B Measure the CIE Lightness (CIE L*) of each step of the step tablet by densitometry (density, converted to reflectance factor, converted to CIE L*), colorimetry (direct CIE L*), or spectrophotometry (CIE L* available through calculation from spectra).

C Enter the measured Lightness values (step B) in a CSV table as [Step# Measured-Lightness-value] pairs.

D Scan this just-measured step tablet according to the scanner setup specified in this Annex, saving the scan data as a non-colour managed RGB file.

E Run an ISO 14524 compliant OECF calibration utility that takes as inputs the RGB format scanned step tablet bitmap (from step C) using the scanner signal channel that shows the largest response to the printed colorant (green channel for neutral printing) and the measured Lightness values of the steps in this step tablet (from step D) to produce a calibration OECF look-up-table (LUT) relating scanner code-value to Lightness for use in Resolution-score measurement.

F The calibration OECF look-up table (LUT) produced in step E.

Figure D.1 — Single colorant scanner calibration

D.5.3 Scanner signal calibration for a process colour printing system evaluation.

In process colour printing system evaluation, printed samples of the Contrast–Resolution test chart are produced by a press system using a standard combination of process colorants. Scanner calibration is to colorimetric aims so as to provide bitmaps of the Contrast–Resolution test chart in a calibrated CIE L*a*b* format for subsequent Resolution-score evaluation. Two different scanner calibration approaches may be taken. If only neutral process colour prints are to be evaluated, either approach will work well. If non-neutral process prints are to be evaluated, the second approach illustrated below will provide more accurate results.

1) Utilizing a standard RGB scanner calibration utility to create an ICC profile for the scanner.

This process, utilized by most scanner colour calibration utilities, is illustrated with the use of a Kodak Q-60 test target (which employs a standard set of colour patches produced using photographic dyes) to create an ICC profile for the scanner. In practice, the reflection colour patch set provided with the scanner calibration utility should be used. This process will create a profile that is fairly accurate for near-neutral colors, but differences in number and spectral shape for the colorants in graphic arts printing and for the photographic dyes used in this calibration can cause some calibration error for scans of graphic arts content with non-neutral colours.

A tolerable error in Resolution-score evaluation is introduced by this calibration process as long as the measurements of the printing system primaries obtained through this calibrated ICC profile differ from colorimetric measurements of the corresponding patches of the scanned printing system primaries by less than five dE. Figure D.2 shows the calibration process.

