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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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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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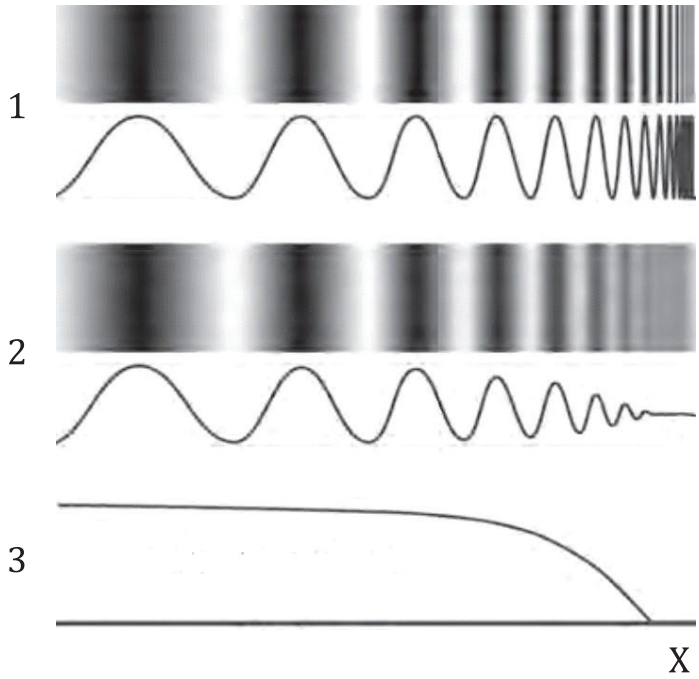
Introduction

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.

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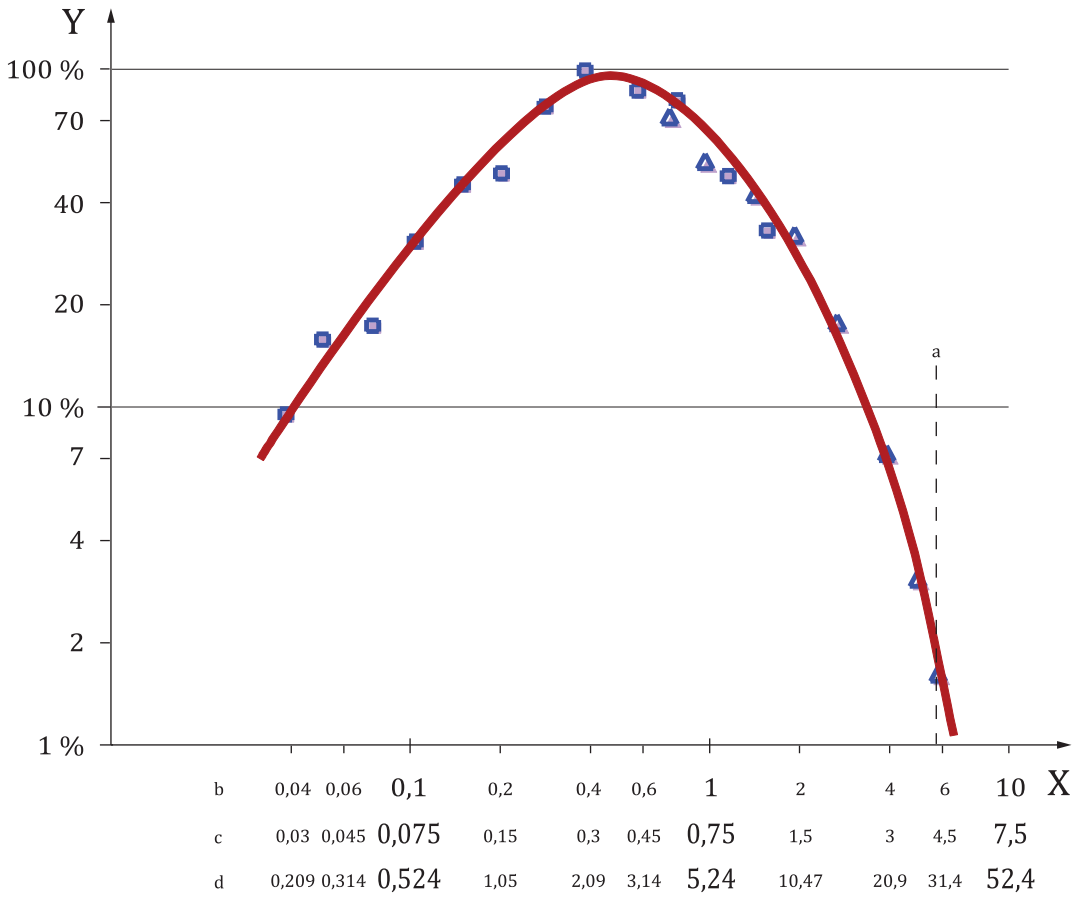
In characterizing perceived resolution, a single component of the imaging chain cannot be isolated since we look at the results of the complete system. The printing system imaging chain starts with the process of placing marks on a substrate. In many printing systems, the individual marks can provide 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

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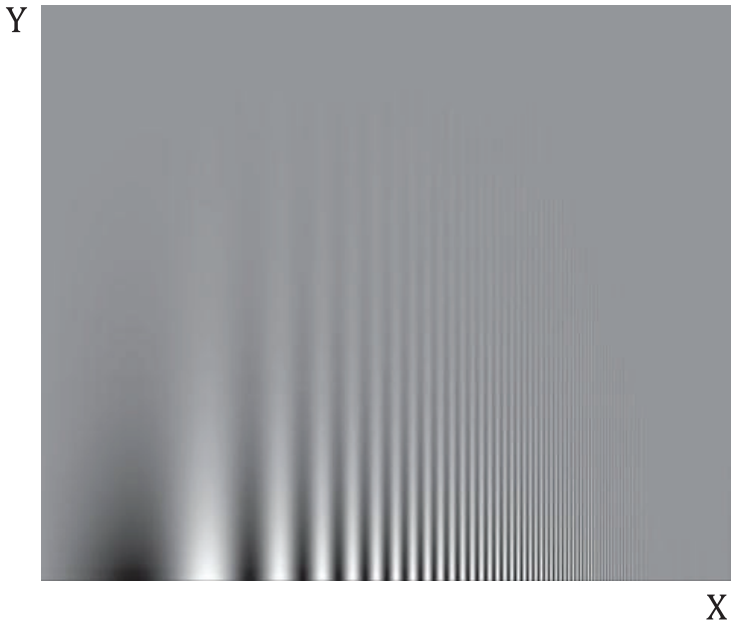
4,5 cy/mm at a viewing distance of 400 mm. At a viewing distance of 400 mm the human visual system response to spatial detail peaks at about 0,4 cy/mm (0,5 cy/mm at 300 mm), decreasing in sensitivity at both higher and lower spatial frequencies.



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].

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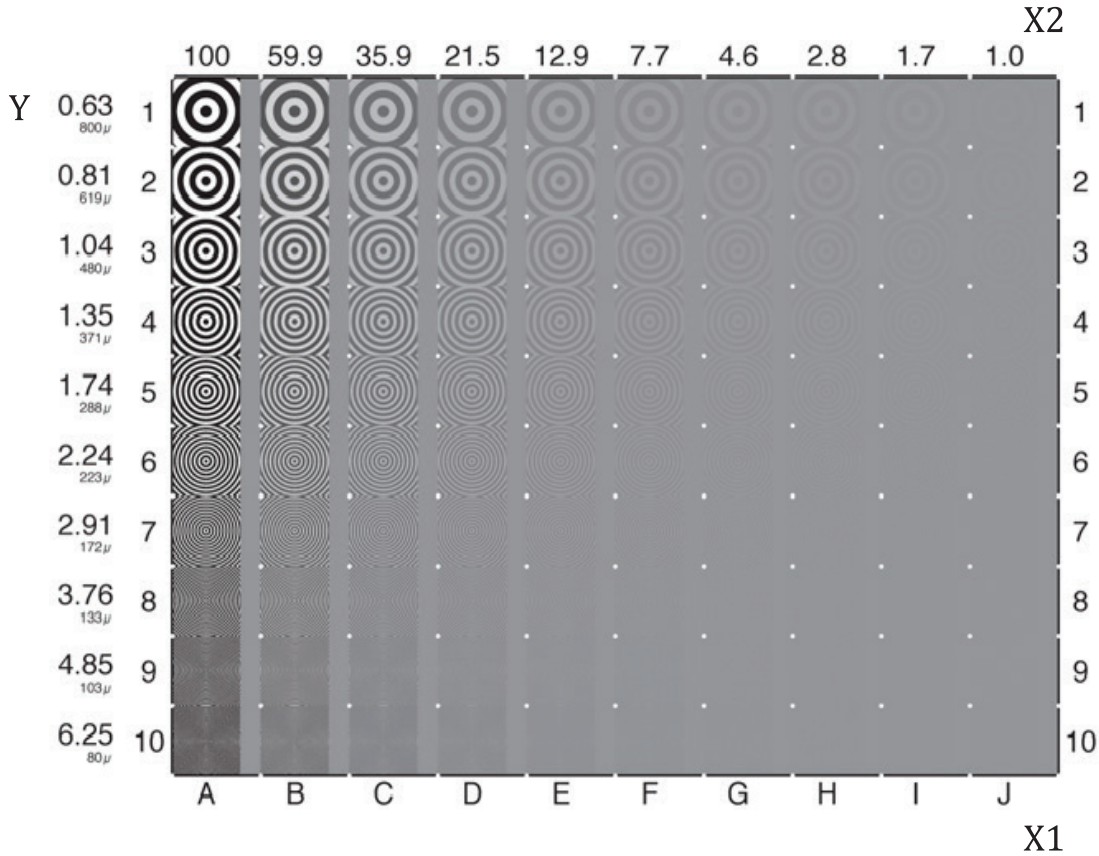

Key

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

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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.

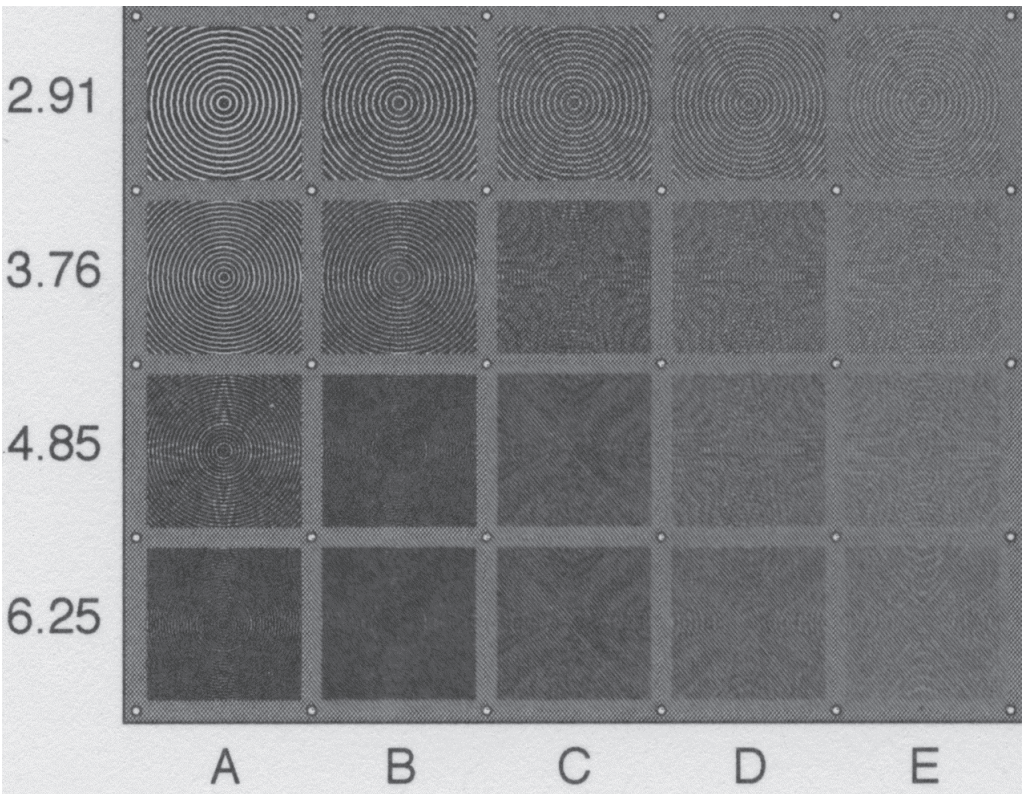

Figure 5 — Enlarged portion of a Contrast–Resolution target print

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 [illegible]

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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.

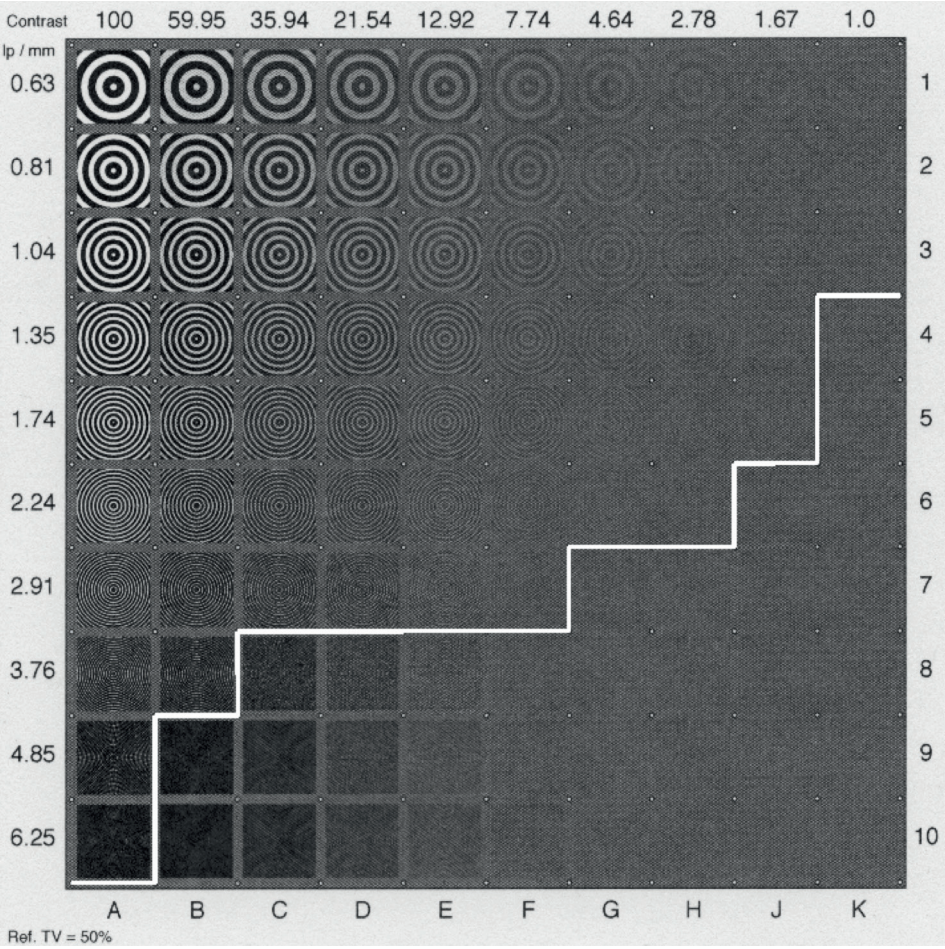

Figure 6 — Enclosed area above an index value threshold curve

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.

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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

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

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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

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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/.

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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/.

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