TECHNICAL REPORT

ISO/TR 14672

First edition
2000-07-15

Graphic technology — Statistics of the natural SCID images defined in ISO 12640

Technologie graphique — Statistique des données d'images en couleur normales (SCID) définies dans l'ISO 12640

Reference number
ISO/TR 14672:2000(E)

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Printed in Switzerland

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this Technical Report may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 14672 was prepared by Technical Committee ISO TC 130, *Graphic technology*, Working Group 2, *Prepress data exchange*.

Introduction

International Standard 12640, *Graphic technology — Prepress digital data exchange — CMYK standard colour image data (CMYK/SCID)*, provides the digital data for a set of natural and synthetic colour images. The natural images are intended for use in subjectively evaluating image quality as a function of image processing and/or output process. In addition, the synthetic images are provided to allow objective measurement of process control, tone reproduction, colour characterization, etc.

In addition, these images may be used for the statistical evaluation of the change in image content as a function of image processing or other imaging steps. TC 130 Working Group 2 agreed to provide a set of reference statistics for these images as a baseline for the technical community wishing to use the images for such statistical evaluation.

This statistical data was prepared by the TC 130 Japanese National Committee, and their efforts have made this technical report possible.

Graphic technology — Statistics of the natural SCID images defined in ISO 12640

1 Scope

This Technical Report provides the colour and spatial frequency distribution statistics associated with the digital image data of International Standard 12640, *Graphic technology — Prepress digital data exchange — CMYK standard colour image data (CMYK/SCID)*.

2 Reference

ISO 12640:1997, *Graphic technology — Prepress digital data exchange — CMYK standard colour image data (CMYK/SCID)*.

3 SCID image description

ISO 12640 defines a set of natural and synthetic colour images, called SCID (Standard Colour Image Data), which can be used for evaluation of image processing algorithms or output devices, and also for colour characterization of output devices.

These images are digital files, encoded in a CMYK format. They exist in two forms, known as the primary and alternate data sets, each of which has different resolutions and data ranges. The primary data set was created using the data encoding scheme typical of a Colour Electronic Prepress System (CEPS). The alternate data set was created from the primary data set by re-encoding the data in the scheme more typically used by the desktop publishing (DTP) prepress systems and defined in ISO 12639 as the P1 profile. With the primary set, tone value of 0% is encoded as data value of 28 and tone value of 100% is encoded as data value of 228; the corresponding data values for the alternate set are 0 to 255. The primary set has an assumed resolution of 16 pixels/mm while the alternate set has an assumed resolution of 12 pixels/mm. The alternate set was computed from the primary set by cubic interpolation combined with a linear mapping of the data values.

The eight natural colour images of the primary set are shown as N1 to N8 in figure 1, the natural colour images of the alternate set are denoted as N1A to N8A. When output at the assumed resolutions of 16 pixels/mm (406.4 pixels/inch) and 12 pixels/mm (304.8 pixels/inch) the resultant size is 160mm x 128mm. The primary set of natural images are 2560 x 2048 pixels and the alternate set are 1920 x 1536 pixels. Table 1 shows the characteristics and typical usage of the images.

These eight images were selected so that users can subjectively evaluate several aspects of image quality that are often reduced by image processing or as a result of output device characteristics. The image quality attributes in question are described in table 1, but may be summarized as follows:

– colour reproduction;

– sharpness;

– graininess.

Although there is no established procedure for quantitative evaluation of these subjective image quality attributes, by the use of a common set of images SCID makes it possible to conduct such subjective evaluation on a consistent basis. However, when evaluating the application of image processing algorithms to the images some quantitative analysis is feasible and in this context various statistical characteristics calculated from the images may prove useful. Statistics on colour and spatial frequency distribution are such basic characteristics.

N1 and N1A

N2 and N2A

N3 and N3A

N4 and N4A

N5 and N5A

N6 and N6A

N7 and N7A

N8 and N8A

Figure 1 — Reduced monochrome reproductions of the natural images

Table 1 — Natural images

Name	Aspect	Characteristics
N1, Portrait	Portrait	Used to evaluate the reproduction of human skin.
N2, Cafeteria	Portrait	Image with complicated geometric shapes. Suitable for evaluating the result of image processing.
N3, Fruit Basket	Landscape	Image of a basket and cloth used to evaluate the reproduction of brown colours and close texture.
N4, Wine and Tableware	Landscape	Image of glassware and silverware used to evaluate the reproduction characteristics of highlight tones and neutral colours.
N5, Bicycle	Portrait	Image of a (penny-farthing) bicycle, resolution charts and other items containing high detail used to evaluate the sharpness of reproduction and the results of image processing.
N6, Orchid	Landscape	Image of an orchid with background vignettes used to evaluate reproduction of highlight and shadow vignettes.
N7, Musicians	Landscape	Image of three girls with different skin characteristics and fine detail used to evaluate the reproduction of different skin tones and image detail.
N8, Candle	Landscape	"Low-key" image of a room scene containing miscellaneous objects used to evaluate dark colours, particularly browns and greens.

These characteristics can be used for the comparison between the data of an original image and that of a transformed or degraded image passing through some image handling system such as an image transmission line, an imaging system, an image storage system or an image transform and processing system. It is also possible to compute those basic quantities from a set of images to certify validity of them if this is in doubt.

Members of the technical committee ISO TC 130 evaluated the aforesaid basic statistical quantities for the eight natural SCID images (for both the primary and alternate set). This technical report summarizes the quantitative results.

4 Colour distribution

Statistics which represent image colour distribution are provided in this section. These were obtained by computing single dimensional histograms, average colour values of each colour, the three-dimensional volume and covariance matrix and resultant orthogonal matrix and principal axes. Such data were calculated for each image. The histogram data is provided graphically (figures 5-12) and numerically (tables 5-12). The remaining statistics are provided in tables 13-20.

It should be noted that each natural image is provided with a text insert such as ISO300 or ISO400 in the image. Pixels representing this text have a coded value of either 0 (white) or 255 (black). This text serves to distinguish between the primary set and alternate set. It is not meaningful to include this text in the colour distribution calculation. Therefore, the calculation was carried out only for the image area, excluding the text.

The position of the outer boundaries of the text is defined by a rectangle produced from the coordinates of two of the corners as shown in figure 2. The position (in terms of number of pixels) of the text in each image is given in table 2 and table 3. This was the area excluded prior to calculation of the statistical data but extended by 4 pixels in each direction to minimize any effects arising from evaluation of the statistics after any image processing which requires calculation based on adjacent pixels. Thus the coordinates of the corners defining the rectangle enclosing the excluded area are $A(X_1-4,Y_1-4)$ and $B(X_2+4,Y_2+4)$.

4.1 Data value histograms and related things

The histograms for the natural images are shown in figures 5-12. These show the frequency of occurrence of each of the dot percent equivalent values within the image; therefore, there are four histograms for each image, one for each of the colours cyan, magenta, yellow and black. Each of the figures has two parts; the first shows the histograms for the primary set of images and the second part the histograms for the alternate set. The numeric data used to produce these figures are given in tables 5-12.

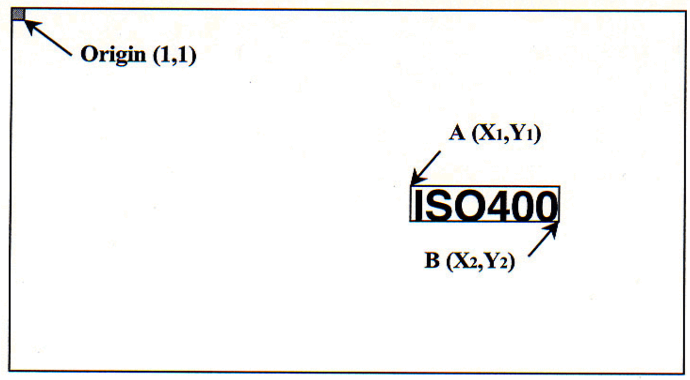


Figure 2 — Definition of the coordinates of the text elements

Table 2 — Position and area of the text for the primary set of natural images (16 pixels/mm)

Image	$A(x_1,y_1)$	$B(x_2,y_2)$
N1	(1769,39)	(2008,88)
N2	(37,35)	(276,84)
N3	(38,36)	(277,85)
N4	(41,37)	(280,86)
N5	(37,34)	(276,83)
N6	(37,35)	(276,84)
N7	(2286,35)	(2525,84)
N8	(2070,193)	(2309,242)

Table 3 — Position and area of the text for the alternate set of natural images (12 pixels/mm)

Image	$A(x_1,y_1)$	$B(x_2,y_2)$
N1A	(1326,24)	(1503,61)
N2A	(26,23)	(203,60)
N3A	(25,22)	(202,59)
N4A	(31,28)	(208,65)
N5A	(25,23)	(202,60)
N6A	(25,23)	(202,60)
N7A	(1708,21)	(1885,58)
N8A	(1554,145)	(1731,182)

It should be noted that although the primary set of images contains data in the ranges 0-27 and 229-255, these are not normally differentiated by the output device since the values less than or equal to 28 are all set to 0% dot and those greater than or equal to 228 are all set to 100% dot. In the case of the alternate set, however, all values in the range may be differentiated. This means that when the alternate set was derived from the primary set all the values in the ranges 0-28 and 229-255 for the primary set were mapped to 0 and 255 respectively. Thus the histograms for the alternate set tend to show very high frequencies for these values when compared to the rest of the values within the image, or the values within the primary set.

This phenomenon has a marked effect on some of the subsequent statistics, depending on the distribution of the 'out of range' values in the primary images. In the case of the average value, for example, it might be expected that the same (or very similar) dot percent value would be obtained for both sets with each of the images. However, this is rarely the case, as will be seen in 4.2, particularly for the black. A glance at the histogram data will quickly reveal why.

Statistics are provided in tables 13-20 for each of the natural images in the set. The data provided are the average colour values of each ink, the three dimensional volume, covariance matrix, resultant orthogonal matrix and principal axes. These are described in more detail in the following subclauses.

4.2 Average colour values

The average colour values may be calculated using equation (1).

$$\bar{c} = \frac{\sum c_i}{N},\ \bar{m} = \frac{\sum m_i}{N},\ \bar{y} = \frac{\sum y_i}{N},\ \bar{k} = \frac{\sum k_i}{N} \qquad (1)$$

where

- c is the value for cyan;
- m is the value for magenta;
- y is the value for yellow;
- k is the value for black;
- i is the index value of the pixel; and
- N is the number of pixels in the image.

The average values indicate the amount of each colour present in an image. Therefore, any tendency for a particular colour to be dominant in each image can be indicated, although not categorically stated, by the average colour values. For example, the high blue content of image N6 and N6A (Orchid) is shown by the fact that the cyan and magenta colour values are higher than those of the yellow. However, similar values would have been obtained from an image containing large areas of cyan and magenta and no blue.

Since no under colour removal (UCR) or gray component replacement (GCR) has been applied to these images black colour is found only in the shadow areas, and the average value is less than that of the coloured inks. However, the magnitude of the value provides some indication of whether an image contains dark colours. For example, the image N5 (Bicycle) contains little black because it consists primarily of clean, but fairly colourful, and light neutral colours. Image N8 (Candle), on the other hand, contains a lot of black because it contains many dark colours, even though many of them are fairly colourful. The black colour quantity is independent of any colour tendency shown by the average of colour values of C, M and Y.

4.3 4 x 4 covariance matrix

The covariance matrix may be calculated using equation (2).

$$[M] = \begin{bmatrix} \frac{\sum (c_i-\bar{c})^2}{N} & \frac{\sum (c_i-\bar{c})(m_i-\bar{m})}{N} & \frac{\sum (c_i-\bar{c})(y_i-\bar{y})}{N} & \frac{\sum (c_i-\bar{c})(k_i-\bar{k})}{N} \\ \frac{\sum (m_i-\bar{m})(c_i-\bar{c})}{N} & \frac{\sum (m_i-\bar{m})^2}{N} & \frac{\sum (m_i-\bar{m})(y_i-\bar{y})}{N} & \frac{\sum (m_i-\bar{m})(k_i-\bar{k})}{N} \\ \frac{\sum (y_i-\bar{y})(c_i-\bar{c})}{N} & \frac{\sum (y_i-\bar{y})(m_i-\bar{m})}{N} & \frac{\sum (y_i-\bar{y})^2}{N} & \frac{\sum (y_i-\bar{y})(k_i-\bar{k})}{N} \\ \frac{\sum (k_i-\bar{k})(c_i-\bar{c})}{N} & \frac{\sum (k_i-\bar{k})(m_i-\bar{m})}{N} & \frac{\sum (k_i-\bar{k})(y_i-\bar{y})}{N} & \frac{\sum (k_i-\bar{k})^2}{N} \end{bmatrix} \qquad (2)$$

The diagonal elements of the covariance matrices in tables 13-20 show the variance of data values for each colour component. The values are related to the range of the histogram in figures 5-12. The non-diagonal elements show the correlation between two colour components. Such a statement may not seem obvious at first, but can best be understood by considering the case where all four separations are identical (c=m=y=k), and hence highly correlated. After normalization by dividing each of the elements in the matrix by the square root of the product of the diagonal elements they will then give a value of 1 for each of the non-diagonal terms. If the colour components are not identical but correlated to some degree, the normalized non-diagonal elements will be smaller than 1. Figure 3 gives an example of a two-dimensional correlation plot with the data values c_i and m_i.

If the distribution has the shape indicated as in (a), there is a high degree of correlation. If the distribution looks as indicated in (b), the degree of correlation is much lower.

Each of the non-diagonal elements in these covariance matrices only shows the correlation between colour components in the image and does not show the degree of colourfulness of the image or the range of colours it contains. For example, a neutral vignette made from the three chromatic inks, and ranging from white to black, would have a very high correlation but is not at all colourful. A similar vignette made from two chromatic inks also has a high degree of correlation, and is very colourful, but the range of colours is very limited. A useful measure of image content is the combination of the range and colourfulness of the colours within it. Such a measure is how widely the colours are distributed within a colour space; in other words how large the colour gamut of the image is. Figure 3 shows this relationship in a two-dimensional space.

4.4 Three-dimensional volumes

To express this measure, it is necessary to define a volume, corresponding to the area shown in figure 3. The volume in the colour space can be determined from the standard deviations along the principal axes of the colour space. These are denoted by σ_1, σ_2, σ_3, σ_4 which are the square roots of the diagonal elements of the covariance matrix after multiplication with the orthogonal matrix shown in tables 13 to 20. In the example, figure 3, the σ can be visualized as the diameters of the ellipse, in the directions ξ and η. In our case, with a CMYK colour space, there are four principal axes, one for each process colour. (It is important to note that this definition means that the relationship between these principal axes and colour is somewhat loose since CMYK is not a true colour space. Nevertheless, it can be shown to produce a reasonable approximation to a uniform colour space and so the following measures do prove usable.) Based on the four standard deviations, the four-dimensional volume V_4, used to show the colour gamut of an image in the full ‘colour’ space produced by the four inks, is defined as follows:

$$V_4 = \sigma_1 \times \sigma_2 \times \sigma_3 \times \sigma_4 \qquad (3)$$

However, since the colour space that humans can sense is only three-dimensional, and the black only adds a limited amount to the colour gamut, V_4 is not always an appropriate measure of the colour gamut. In this report, the three-dimensional volume V_3 is proposed as a quantity to evaluate the colour gamut of an image.

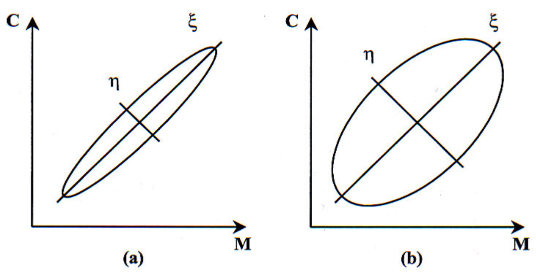
V_3 is obtained as a product of three standard deviations, excluding the minimum standard deviation:

$$V_3 = \sigma_1 \times \sigma_2 \times \sigma_3 \qquad (4)$$

According to the tables, the image among the eight with the largest gamut is N2 and that with the smallest is N4. These results are consistent with subjective assessment.

It should be noted that all the quantities above are defined in terms of *c*, *m*, *y* and *k* coordinates. It should not be expected that a colour gamut measure derived from CMYK space corresponds exactly to the gamut as perceived by a human observer, as would be expected from such measures derived from CIELAB or CIELUV space.

However, the SCID images are defined as CMYK images in digital form. Their reproduced colour depends on the specific inks and processes used for printing, and these images are intended for use by all processes. Thus there is no single set of colorimetric data which could be specified and so there was no alternative than to use CMYK colour space for this evaluation. Tables 13-20 show the statistics on colour distribution of each image.



(a) high correlation (b) low correlation

Figure 3 — Distribution of colour values

5 Spatial frequency characteristics

To evaluate the spatial frequency characteristics of the test images, the autocorrelation function R(a,b) defined by equation (5) was calculated for each image.

$$R(a,b)=\frac{\sum\sum\left[f(i_x,i_y)-\overline{f_{i_x,i_y}}\right]\left[f(i_x+a,i_y+b)-\overline{f_{i_x+a,i_y+b}}\right]}{\left[\sum\left\{f(i_x,i_y)-\overline{f_{i_x,i_y}}\right\}^2\sum\left\{f(i_x+a,i_y+b)-\overline{f_{i_x+a,i_y+b}}\right\}^2\right]^{\frac{1}{2}}} \qquad (5)$$

where

$R(a,b)$ is the autocorrelation function;
a is the horizontal shift from point(x,y);
b is the vertical shift from point(x,y);
i_x is the horizontal image coordinate; and
i_y is the vertical image co-ordinate.

The way the image area used to calculate the autocorrelation function was defined is shown in figure 4. The specific coordinates for each image are given in table 4. Figures 13-20 show the autocorrelation function $R(a,0)$ (solid line) and $R(0,b)$ (dotted line) of the c, m, y and k components of each picture. Each value is normalized by $R(0,0)$, the value of for shift $R(0,0)$.

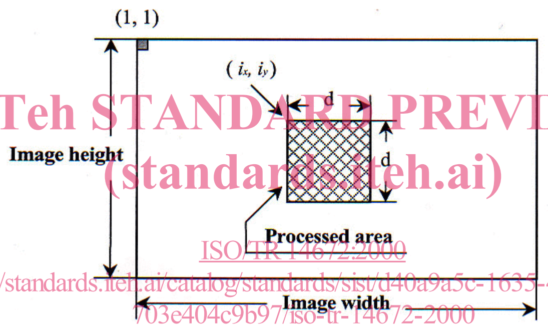


Figure 4 — Definition of the area used to calculate the autocorrelation function

Table 4 — Coordinates of the processed area for each image

Image	i_x	i_y	d
N1	513	769	1024
N1A	385	577	768
N2	513	769	1024
N2A	385	577	768
N3	769	513	1024
N3A	577	385	768
N4	769	513	1024
N4A	577	385	768
N5	513	769	1024
N5A	385	577	768
N6	769	513	1024
N6A	577	385	768
N7	769	513	1024
N7A	577	385	768
N8	769	513	1024
N8A	577	385	768

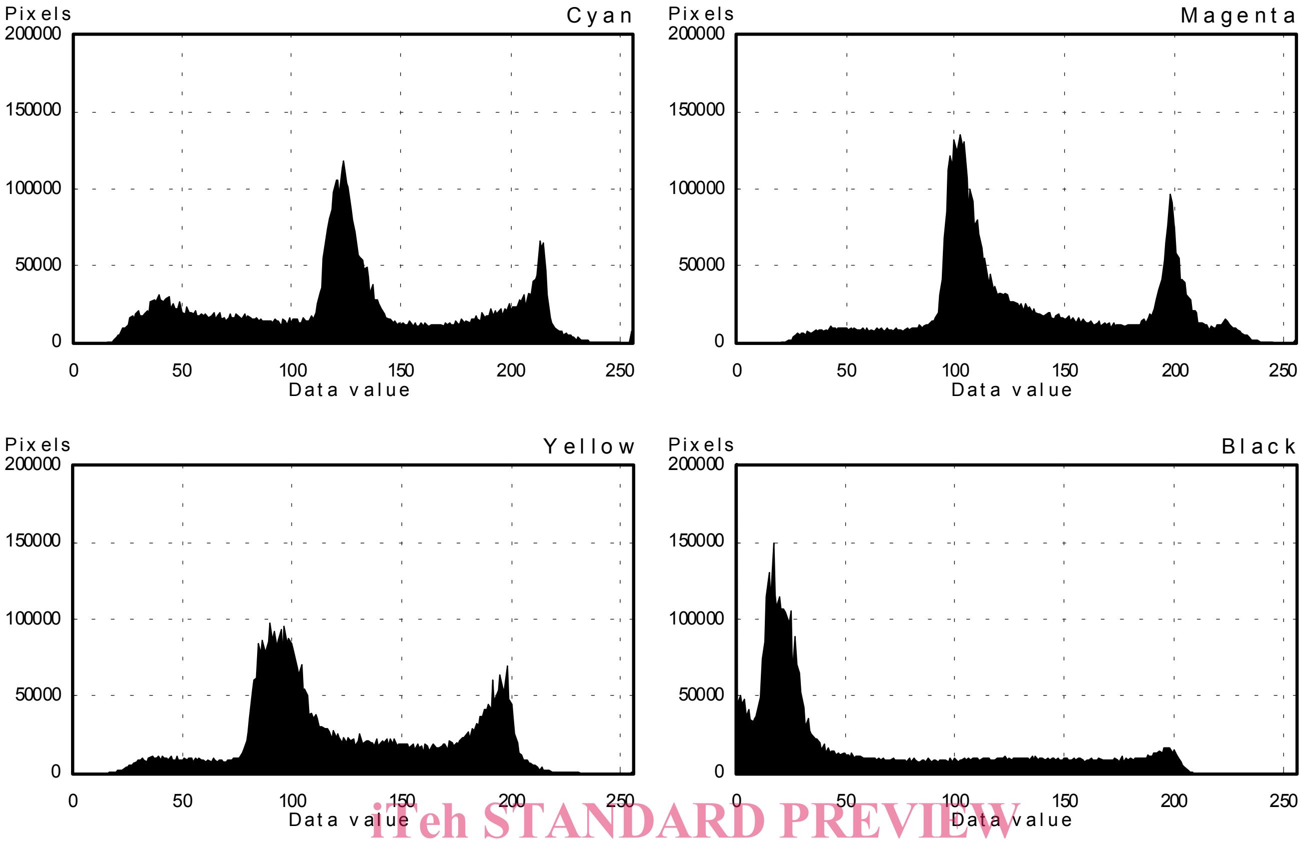


Figure 5a — Histograms for image N1

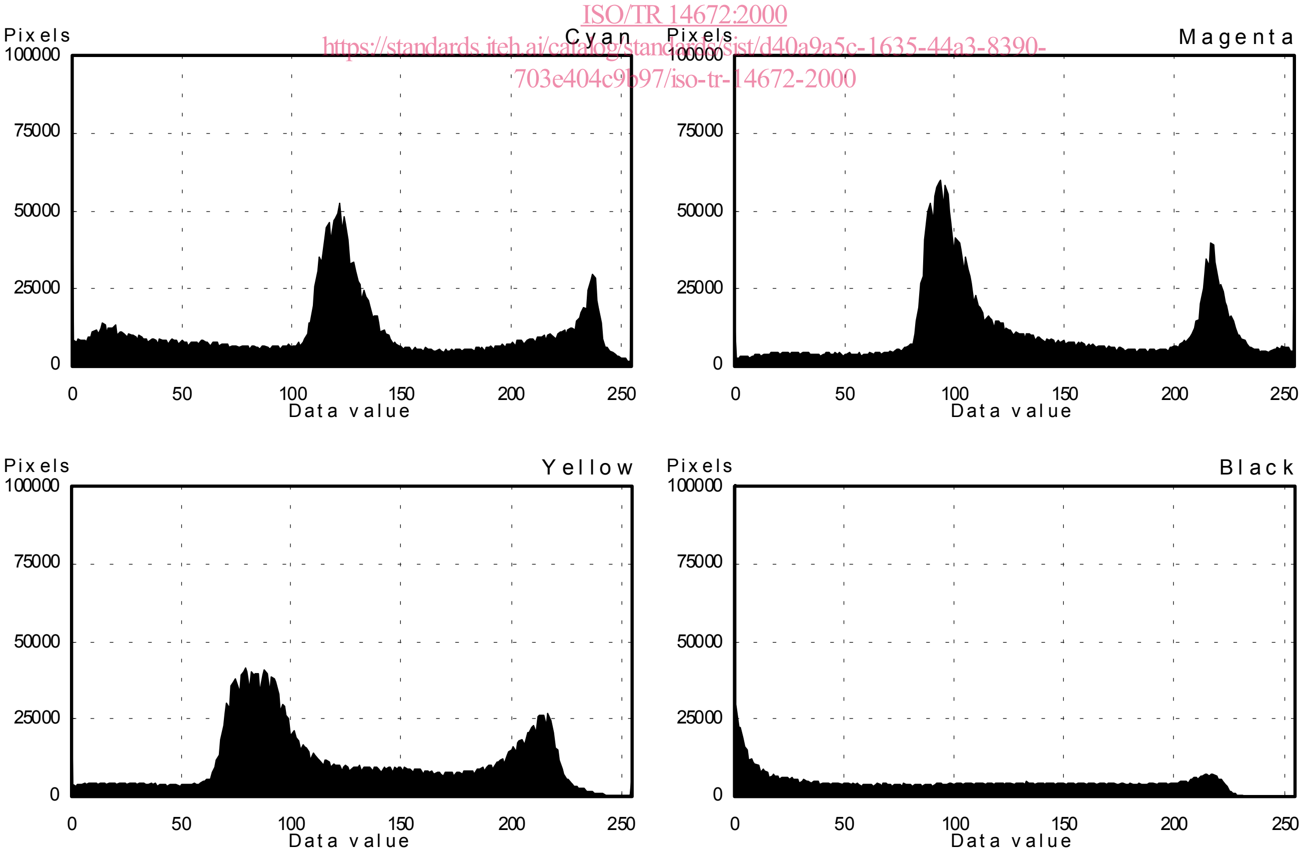


Figure 5b — Histograms for image N1A

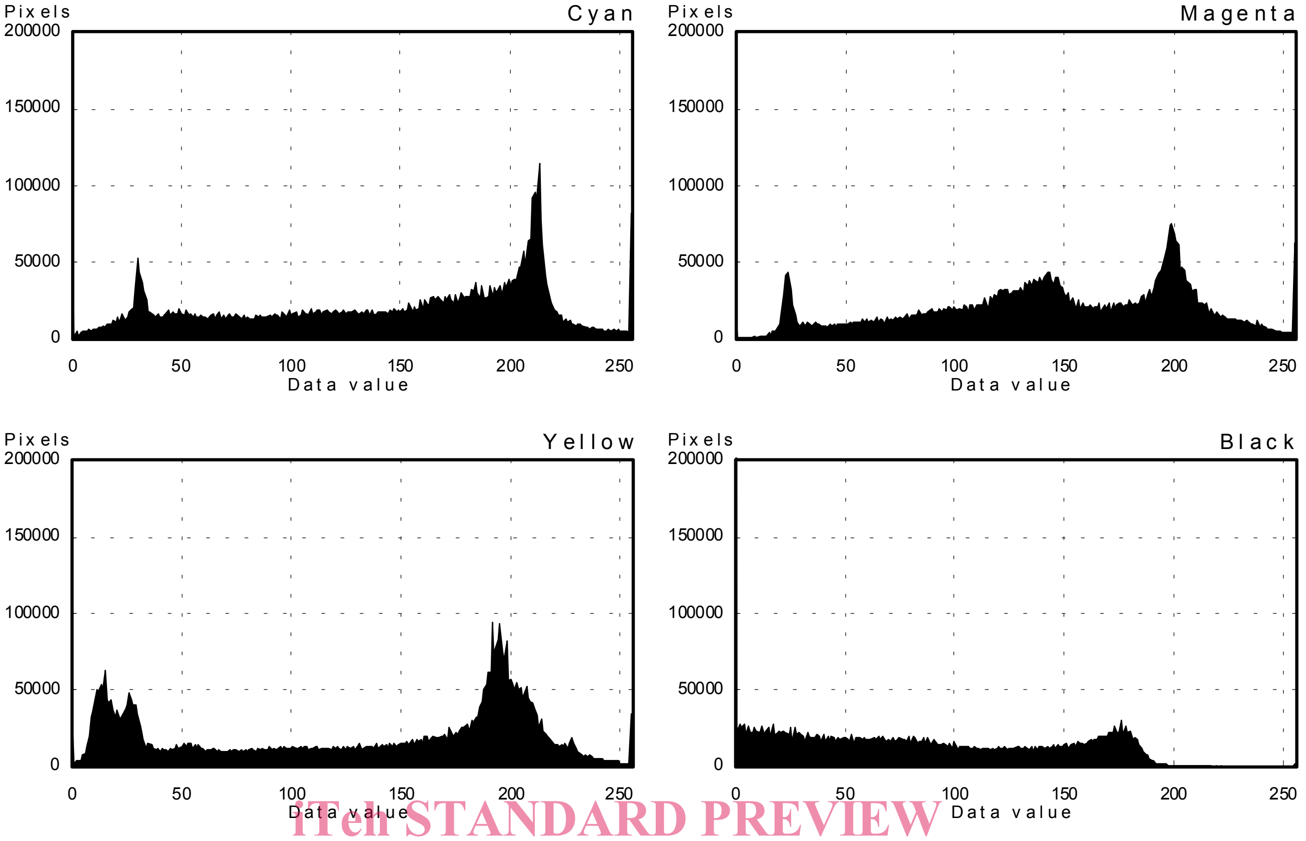


Figure 6a — Histograms for image N2

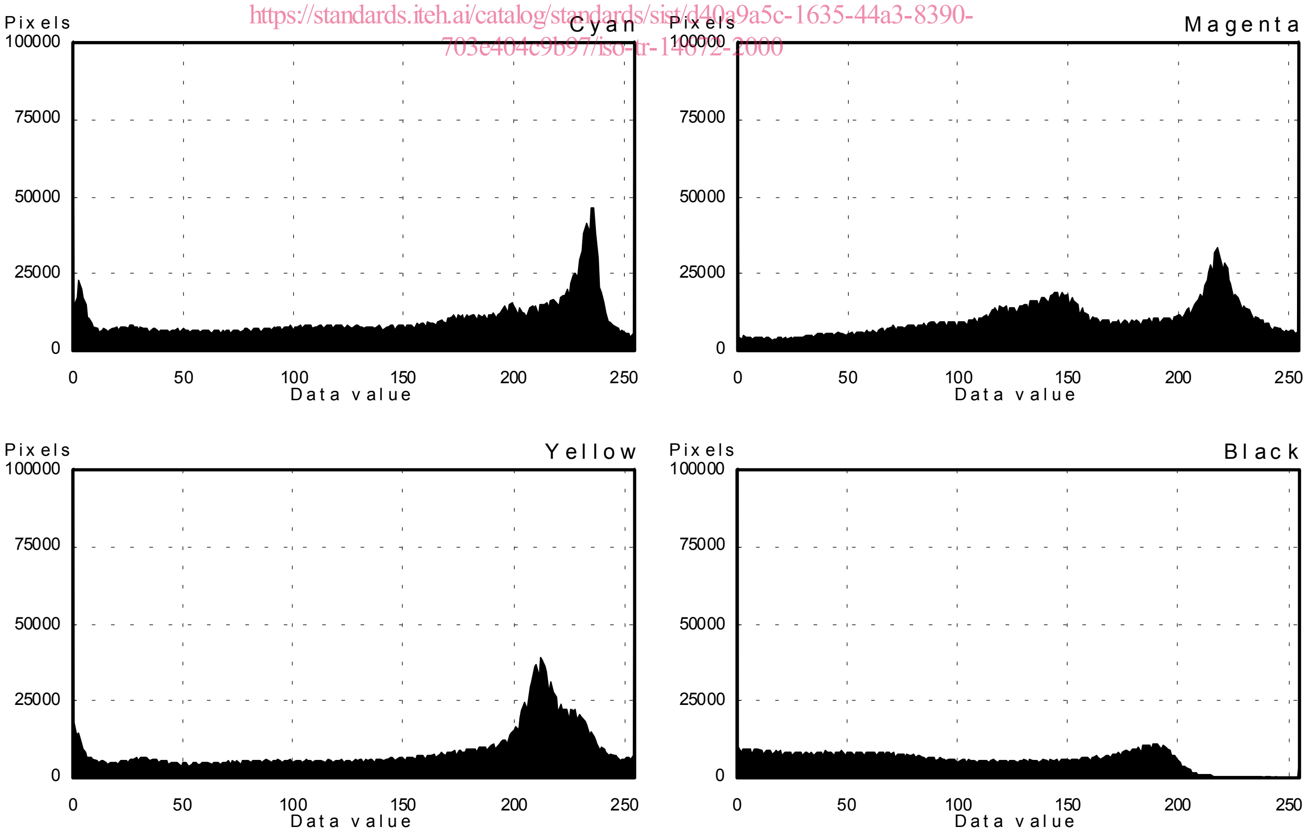


Figure 6b — Histograms for image N2A