Colour image evaluation systems

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Judging the quality of an image involves both subjective evaluation based on human visual skills, and objective evaluation expressed in terms of physical quantities. Subjective evaluation may, for example, use a method where limit models are created and the quality of printed samples is assessed by comparing them visually with these limit models, but the repeatability of this judgement differs between individuals and the process also affects work efficiency.[1] Yet the problems of consistency and efficiency can be overcome provided that the evaluation results can be expressed as measurement values.

In particular, if the judgement criteria for image quality can be managed on the basis of statistical measurement values, in each of the respective stages of product planning, research, development, design, manufacture and maintenance, then the manufacturer becomes able to offer products of stable quality to the end user on a consistent basis. In this respect, the key issue as far as we are concerned is to develop a simple and inexpensive image evaluation system.

Quality assessment in colour images involves a whole range of factors, such as: colour reproduction range, tonal graduation, apparatus-related colour changes over time, colour uniformity (colour irregularities), lustre, granularity (graininess), colour aberration, print position accuracy, pitch variation, noise factors (fogging, specking, bands/stripes, ghost images, blurring, smudging, etc.), image resolution, sharpness (text/line clarity), and more besides.

Many different colour measurement systems are available commercially. These range from simple handheld colorimeters, to more advanced colorimeters with an X-Y scanning function capable of taking automatic readings, as well as meters which can take high-speed readings of some 900 patches per minute, in the X direction only. We use each of these types of device, depending on the particular application.

This article presents the image evaluation system we have developed to date, which extracts what we consider to be the more important of the image quality factors that are dependent on subjective judgement, and allows these factors to be measured in terms of quantitative values.

This image system is currently being used in our product development and design stages, where it is producing good results. It is also used in factory testing processes, thus helping to stabilize the quality of our shipped products.

An overview of the colour image evaluation system

Fig. 1 shows the general composition of this system, which is built by simply connecting a standard commercial colour scanner (1) to a PC (2). A print sample (3) is mounted on the scanner, the PC instructs the scanner to scan the print sample, and the image data of the print sample is converted to digital data. This digital data is read into the computer via a cable (4). The image data of the print sample read into the computer is then analysed by software processing, and the measurement values for the image are calculated.

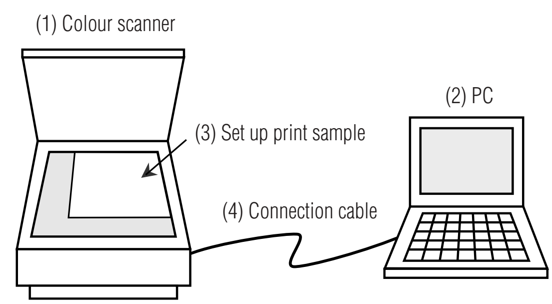

Fig. 1 Simple image evaluation system

We used a scanner with a maximum resolution of 1600 dpi, but in general, the higher the resolution, the slower the scanning speed. Therefore, an optimum resolution should be set for each particular objective.

Below, we describe methods for measuring colour aberration, fogging, granularity (graininess), CTF (resolution), and pitch variation.

Colour aberration

Colour aberration is one of the problems associated with tandem type printers. Because the colour image is formed directly onto the medium in a progressive fashion, it follows that any fluctuation in the medium feed rate will cause divergence in the print positions for each colour. Available tandem colour printers are built in with automatic colour aberration correcting functions, but issues of component precision, and the like, mean that it is difficult to correct aberration completely, and colour aberration of the order of 100 μm is seen to occur.

The causes of colour aberration are various: variation in the medium conveyance speed, variation in the resist speed, variation in the fixing speed, the precision of the drive gears, eccentricity in the photosensitive drum, load fluctuation, expansion of components due to temperature rises, etc. Analysing these many causes requires means for measuring the colour aberration quickly and efficiently.

Fig. 2 shows a pattern used for measuring colour aberration. The colours, K (black), C (cyan), M (magenta), Y (yellow) are arranged equidistantly in sequence over the colour aberration pattern, whilst below it, only K is listed, again at equidistant intervals.

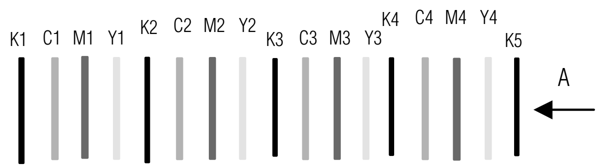

Fig. 2 Colour aberration pattern

Taking account of the scanning speed, the scanner resolution was set to 400 dpi (400 dots per inch) and the colour aberration pattern was scanned. Fig. 3 shows the reading for the black lines (K) only, extracted from a reading taken at position A shown in Fig. 2. The horizontal axis shows dot positions in 400 dpi units (63.5 μm), and the vertical axis represents the scanner output value (brightness) for each dot. The regions of high brightness indicate white areas of the colour aberration pattern, and the regions of low brightness indicate black lines (K). The positions can also be calculated by measuring the pitch between the dots of low brightness, but the accuracy of this will be 63.5 μm.

In order to increase the colour aberration accuracy, three dots of low scanner brightness are sampled, as illustrated in Fig. 4, an approximation curve is derived from these three brightness values, and the minimum brightness is calculated. Through this method, the position of each line can be predicted in micron units. These positions are stored as K1, K2, ..., Kn.

The other colours scanned in line A are also extracted and measured, in the same way. For example, the respective positions of the C (cyan) lines, C1, C2, ..., Ci, ..., Cn are calculated from three points of low brightness on the C line.

The K position corresponding to position C1 is written as (K2-K1) / 4. The amount of colour aberration of C with respect to K, ΔK/Ci is derived by:

$$\Delta K/Ci = Ci - Ki - (Ki + 1 - Ki) /4$$

The amount of colour aberration of M and Y with respect to K, namely, ΔK/Mi, and ΔK/Yi, can also be found by similar equations.

$$\Delta K/Mi = Mi - Ki - 2 \times (Ki + 1 - Ki) /4$$

$$\Delta K/Yi = Yi - Ki - 3 \times (Ki + 1 - Ki) /4$$

Fig. 5 shows graphs of the calculated colour aberrations, which indicate a clear periodicity in the colour aberration. By subjecting this data to frequency analysis, it is possible to deduce the causes of this aberration. The colour aberration quantities measured using this image evaluation system very closely match those obtained manually using an optical microscope.

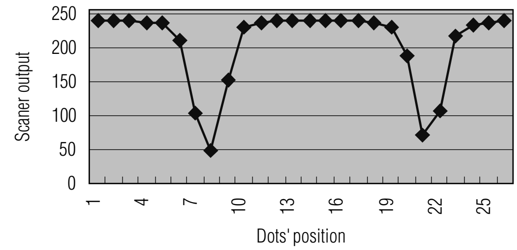

Fig. 3 Scanner readings

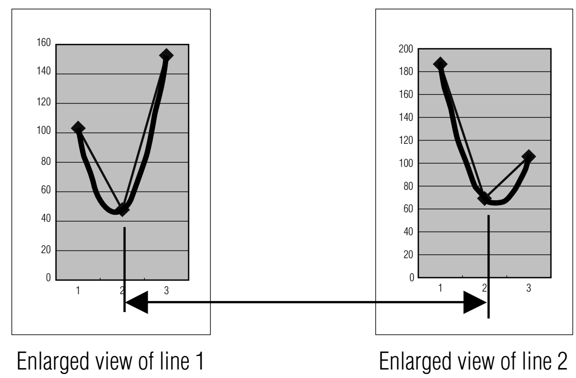

Fig. 4 Enlarged views of line 1 and line 2

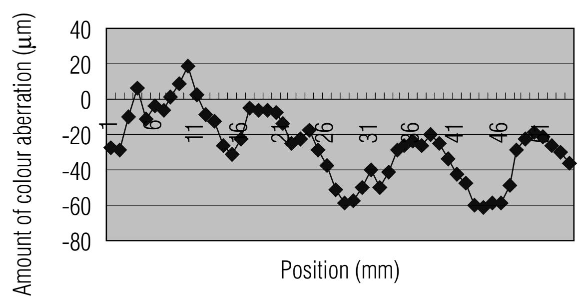

Fig. 5 Periodicity of colour aberration

Fogging

"Fogging" describes the phenomenon where trace quantities of toner are transferred to the white parts of a page, which are in principle to be left unprinted, causing soiling of the white parts and giving them a grey appearance. Fogging is an important parameter when evaluating the overall quality of an image. One assessment method indicates the level of background soiling by comparing the density value of a white part of a print sample, and the density value of the white part of an unprinted sheet. However, since the slight traces of toner create a grey colour, the density value hardly differs from that of the original white and in many cases, a comparison of physical quantities is not feasible. Therefore, in practice, a set of limit models are prepared and the print sample is compared to these to make a subjective assessment. As stated previously, subjective evaluation methods involve a range of problems. Furthermore, differences in toner particle size mean that the same toner density may result in a different appearance, thus leading to further problems in evaluation.

Fig. 6 shows a graph of the brightness reading distribution obtained when the fogged part of a print sample is scanned (at 1200 dpi resolution, monochrome mode). Since a small quantity of toner is distributed over the paper surface in the fogged region, the brightness reading for the region marked by toner is lower than that of a pure white region, whereas the white paper area where no toner is present has a higher brightness value.

Taking D to be the average of all the brightness values, the standard deviation σ is determined as follows.

$$\sigma = \sqrt{\{\Sigma(Di - D)^2\} / (N - 1)}$$

Here, N is the total number of brightness samples, and Di is the respective brightness value read by the scanner. By finding σ, the variation from the average value can be derived. If the number of low brightness values increases, then the variation of the brightness value will also increase, leading to a larger value for the standard deviation σ.

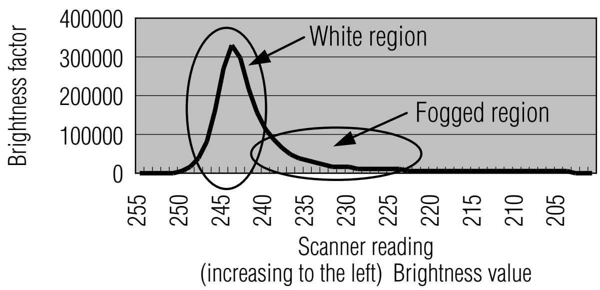

Fig. 6 Brightness distribution of fogging sample

We studied the possibility of substituting the standard deviation σ as a physical quantity representing the level of fogging. We took the fogging limit samples we had been using so far and scanned them into our image evaluation system, to find out the standard deviation σ. The relationship between σ and the limit sample level is plotted in Fig. 7.

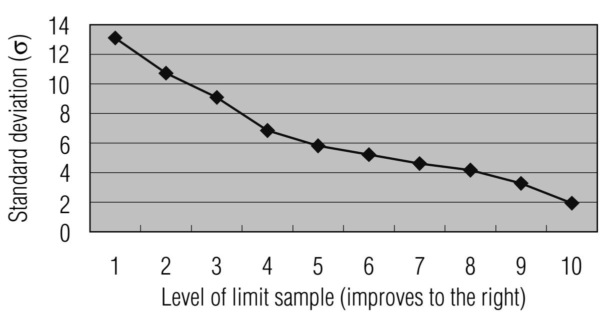

Fig. 7 Relationship between limit sample level and standard deviation σ

This relationship was stored in the PC and the measured σ values were converted to limit sample levels. In this way, it was possible to achieve continuity from the limit sample method used to date, at the same time as moving from a subjective analysis system, which involves individual errors, to an objective judgement process based on measurement values.

Granularity (graininess)

Just as noise in audio devices causes a deterioration in sound quality, noise also degrades quality in images. In electrophotography, the toner particles are relatively large compared to silver halides, print, etc., and hence the dots formed by the toner on the paper are distributed in a granular fashion. There is also wide variation in the particle size, which can give the image a rough appearance. This roughness, or noise, is known as granularity (graininess), and is one of the most important parameters in evaluating colour image quality.

Since this granularity represents variation in the toner particle distribution, then provided that the variation in the density distribution of each dot, in other words, the standard deviation σ, can be determined, it becomes possible to measure the granularity.

This requires the capacity to detect toner dust, for example, and therefore a scanner with maximum resolution of 1600 dpi is used.

Fig. 8 shows an enlarged view of the image data read from the scanner. In an actual print-out, the lines of dots are arranged at a slight inclination, known as the screen angle, as illustrated, and this screen angle must be determined. Firstly, the point of minimum brightness (maximum density) in the central region of the image data is found. In Fig. 8, this corresponds to the black dot inside the shaded area (the central dot is enclosed within the shaded area). The sums of the brightness values read at respective angles from this central point are calculated, and by finding the sums having the lowest values, two screen lines are identified. In the example shown in Fig. 8, these are θ1 = 7.125° and θ2 = 97.125°.

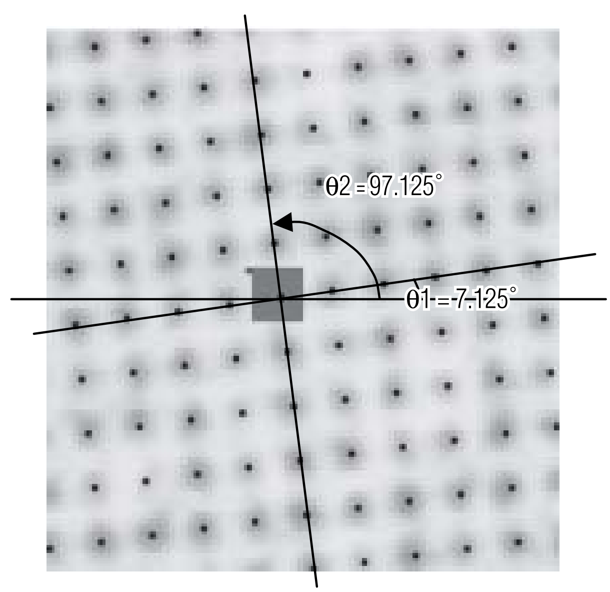

Fig. 8 Enlarged view of image data

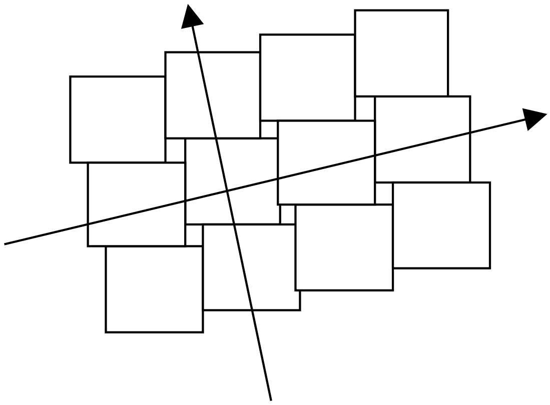

Fig. 9 Schematic view of screen

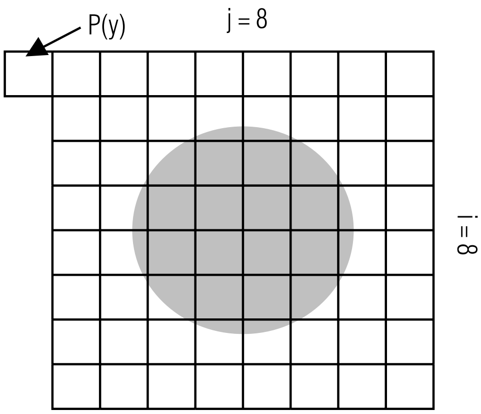

Fig. 10 Relationship between frame and pixels

Fig. 9 shows a schematic illustration of this example, and Fig. 10 shows an enlargement of the central shaded area in Fig. 8. The individual grid squares shown in Fig. 10 correspond to the scanner pixels.

In the example in Fig. 10, one dot is made up of 8 x 8 + 1 = 65 pixels. The density value D' for each dot is calculated from the brightness values P (i, j) for each of the pixels in the dot. Density is represented as the logarithm of the light reflectivity. From this definition, the following equation can be derived. Incidentally, the density value does not have any unit.

$$D' = -\log [\{\Sigma P(i, j) + P(y)\} / (65 \times 255)]$$

(i = 1 to 8, j = 1 to 8, P(y) • • • See Fig. 10)

Having found the screen angle, we can then work out the density values of each of the frames shown in Fig. 9, using the same equation.

A standard deviation σ' indicating the density variation is derived from the calculated density values Dn for each dot, and the average of all the density values, Ave.

$$\text{Ave} = (\Sigma Dn) / N \quad N : \text{Total number of dots}$$

$$\sigma' = \sqrt{\{\Sigma(\text{Ave} - Dn)^2\} / (N - 1)}$$

A large value for σ' indicates that there is a large variation between the respective dots, in other words, that the image has poor granularity (graininess).

We scanned in print samples with respective densities of 0.15, 0.22, 0.29 and 0.35, and determined the σ' value for each sample. The resulting relationship between the density and σ value is plotted in Fig. 11.

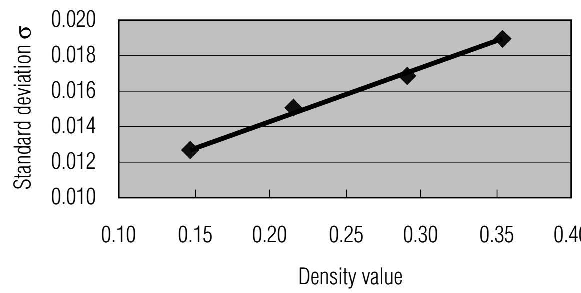

Fig. 11 Relationship between standard deviation σ and density

Fig. 11 shows that σ is directly proportional to the density value. Based on this relationship, we converted the calculated σ' values to a σ value corresponding to a density of 0.30. Even when the same half-tone image is printed on different manufacturers' printers, there will be some variation in density due to the device characteristics. In order to be able to compare our printers with other machines, we used the σ value for 0.30 density to represent granularity (graininess).

Until now, we have assessed granularity (graininess) by comparison with limit samples. In order to achieve a smooth succession from this method, we found the σ values for our level 3 - 10 limit samples. The corresponding results are illustrated in Fig. 12, and they demonstrate an inversely proportional relationship.

Similarly to assessment of fogging, the measured σ values are used by converting them to the values of the limit sample levels.

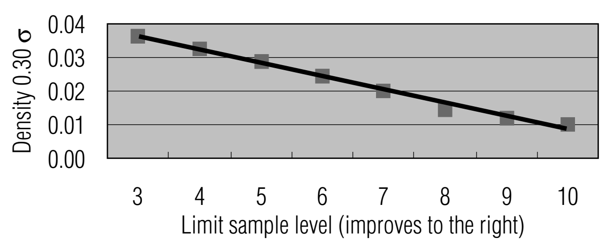

Fig. 12 Relationship between limit sample level and σ

CTF (Resolution)

CTF is an acronym for "Contrast Transfer Function", a key index of print quality, which is used to study the actual resolution capacity of a printer.

CTF is calculated by printing out an image of a group of lines, spaced equidistantly at very small intervals (e.g., 0.1 mm), as shown in Fig. 13.

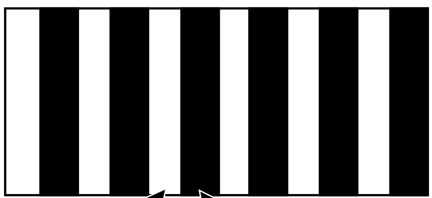

Fig. 13 CTF pattern

The print sample is then read in by a scanner and the CTF is expressed by the following equation, where Dmax is the line density of the black regions, and Dmin is the density of the white regions of the paper between the lines.

$$CTF = \frac{Dmax - Dmin}{Dmax + Dmin} \times 100$$

However, measuring these density values with standard density measuring equipment requires the use of a very expensive microdensitometer, and the larger the group of lines, the longer the measuring time needed.

Our image evaluation system is able to measure a large number of lines at the same time, even if the line-to-line gaps are very small.

If the digital data (brightness values) received from the scanner is converted to density values and plotted on a graph, then the waveform in Fig. 14 is obtained. The peaks correspond to Dmax values, and the troughs, to Dmin values. The CTF value can therefore be found from respective Dmax and Dmin pairs.

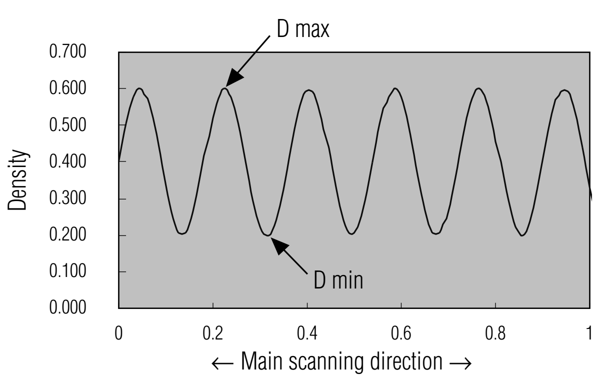

Fig. 14 Density of line group

Pitch variation

One of the issues in print quality is the striping or banding that can occur at very narrow intervals as illustrated in Fig. 15. This is called pitch variation, and in many cases, it is caused by the drive components in the printer mechanism (e.g., the motor, gears, rollers, etc.). If this phenomenon occurs, then it is necessary to investigate whether there are any problems in the drive system.

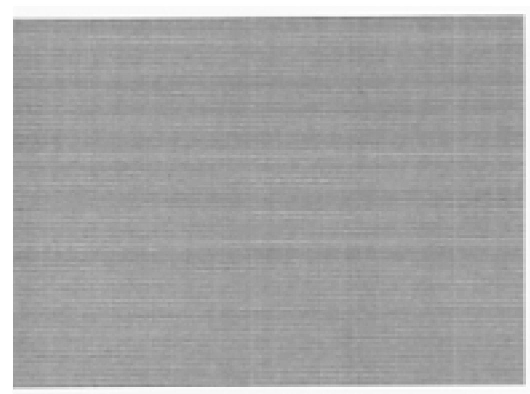

Fig. 15 Sample containing pitch variation

Our image evaluation system is also capable of investigating the causes of pitch variation, by scanning in a print sample showing signs of this problem and then analyzing the measurement data by means of a Fourier transform calculation.

The Fourier transform is a calculation method used widely in the field of signal processing[2] to investigate signal frequency characteristics. The sampling data in the signal is put through a series calculation to create a spectral diagram, which is then used to examine the frequency characteristics of a phenomenon.

In the image evaluation system, the digital data generated by the scanner is used as sampling data, and by performing a Fourier transform of this data, the periodic effects occurring in the image can be analysed from the frequency characteristics.

Fig. 16 shows the spectral diagram created by the image evaluation system as a result of processing a print sample formed by dots of 85 μm pitch, which contains pitch variation.

In the graph, a peak can be observed at a cycle of 85 μm, and this peak is generally known as a power spectrum. The power spectrum at 85 μm indicates the dot pitch of the print sample. In ideal conditions, only the power spectrum indicating the dot pitch is observed, but here, there is another power spectrum at a cycle of 0.37 mm, which represents the pitch variation. From this, we can tell that the pitch variation is caused by a drive component (gear, roller, etc.) with a cycle of 0.37 mm, which is affecting the print image in some way.

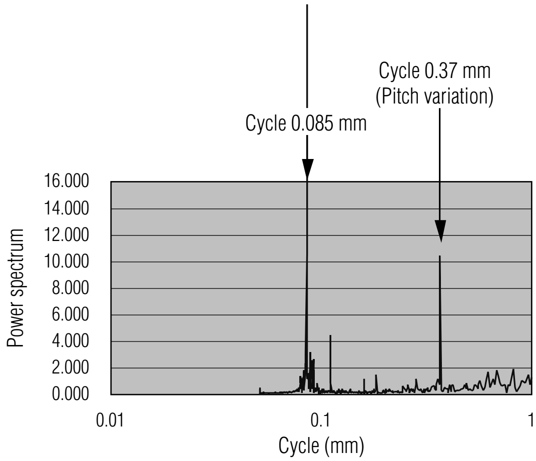

Fig. 16 Spectral diagram

Conclusion

Our colour image evaluation system allows us to measure the main factors in image assessment. In the future, we aim to increase the evaluation factors handled, moving towards a complete image evaluation system which is also capable of judging aspects of image quality that relate to psychological factors (for example, an "attractive" or "messy" image, the quality of image contrast, whether an image has depth or appears flat, and so on), on the basis of quantitative measurement values.

References

1) The Society of Electrophotography of Japan, ed.: "Electrophotography Technology: Fundamentals and Applications", Corona-sha, p.704

2) Shogo Nakamura: "Digital Fourier Transform", Tokyo Denki University Press, pp. 2-7

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