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Automatic gravure print feature determination at production speeds

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Abstract: This paper describes the development of a non-contact system for measuring the colour of printed material at web speeds, in addition to gravure-printed dot feature recognition. The system proposed uses a non-contact spectrophotometer based on a holographic grating, in conjunction with a conventional monochrome area scan camera, from which colour spectral data are extracted, while a xenon flash is used to illuminate colour samples. Dot features are captured by a magnification lens, in conjunction with a progressive scan camera. Software and hardware details of the system are given, together with the underlying mathematics for colour space conversion and measurement. Conversion equations from X, Y, Z chromaticity coordinates to the RGB system are presented, and also equations to convert from the $L^*a^*b^*$ colour space to X, Y, Z chromaticity coordinates. Experimental results are presented whereby the non-contact spectral system is shown to perform to a colour tolerance exceeding that of conventional colour video systems, and where performance of the dot feature system is comparable with traditional static examination methods using a microscope.

Keywords: colour, video, measurement, precision, spectral

NOTATION

CIE	Commission Internationale de l'Éclairage (International Commission on Illumination) [1]
k	normalizing factor [CIE 1964 standard (unitless)]
L, a, b	CIE standard colour space coordinates ($L^*a^*b^*$ system) (CIE standard units)
$L_{1,2}, a_{1,2}, b_{1,2}$	CIE standard colour space coordinates where the subscripts denote different colour space sets for comparison (unitless)
R, G, B	red, green and blue colour contents respectively (unitless, scale 0–100: CIE)
$S(\lambda)$	relative illuminant spectral power distribution (unitless)
$\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$	CIE 1964 supplementary standard colorimetric system tristimulus values (CIE standard units)

X, Y, Z	CIE standard chromaticity coordinates (XYZ system) (CIE standard units)
X_n, Y_n, Z_n	illumination reference stimuli (XYZ system) (CIE standard units)
ΔE	CIE standard colour difference (CIE standard units)
λ	wavelength (nm)
$\varphi(\lambda)$	colour stimulus function for spectrum measured [CIE standard (nm)]

1 INTRODUCTION

In gravure printing, small holes (cells) on the surface of a print cylinder are filled with a free-flowing ink, the rest of the cylinder surface is wiped clean and the cylinder is rolled against the web (often paper), which absorbs the ink out of the cells. Gravure printing consequently builds up images using tiny dots, whose size and shape can reveal a wealth of information about process health. A typical process is that of wallpaper printing. In order to determine the stability of the printing process, these dots may be examined for shape defects and for colour drift using laboratory microscopes and bench top spectrophotometers. Currently, this function is achieved by

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physically removing sections of paper from the printing run and undertaking off-line analysis by skilled laboratory technicians [1–3]. This is a disruption to the printing process, associated with long delays (of the order of hours) before a decision can be made on how to adjust the printing process parameters [4]. This leads to under-utilization of expensive process plant [4] (wallpaper printing systems for five colours are typically £500 000). Manufacturers invest in over-capacity provision of process plant in order to achieve the required production volume on many under-utilized machines. The second major problem associated with this approach to print quality control is the production of defective printed product (waste) during the stopping and starting of the process. This waste product can be many thousands of metres for high-speed machinery such as wallpaper printing where the web speed is typically 2 m/s. When a print job is being run for the first time, the waste product generated during set-up tests can reach kilometres in length. This is mainly due to the number of process variables involved and the complexity of their interaction. Subsequent print runs of the same product still generate substantial waste. Human operators find this sort of challenge very frustrating in a day-to-day production environment. Some operators are better than others at meeting this challenge. An added complication is that operators often use different process settings to achieve the same result. This variance leads to stoppages at changeover times between shifts while operators apply the ‘black art’ of their trade. Thus resulting in yet more waste product. All this waste product must be disposed of in an environmentally acceptable way. The combination of under-utilization of expensive print lines and the associated waste product disposal costs results in losses of more than £1 million p.a. in a medium-sized printing company. Modern printing machinery utilizes machine vision to capture ‘images’ of the printed pattern for registration inspection and general print fault detection. These systems have made significant impact on reducing defective product leaving the factory gate to customers. A reduction in lead times would have significant advantages to the gravure industry which is tending towards short production runs [5]. The ideal goal would be to have a printing process that automatically sets up and never produces any defective product. This is the first publicized worldwide research to use non-contact spectral imaging for the inspection of printed material, as an indicator of process health, and this has required original research which has been described in this paper. This is also the first publicized worldwide research to use machine vision to examine gravure dot features to infer printing process variables on line. The work described in this paper is a step towards achieving these objectives.

2 CONVENTIONAL COLOUR VIDEO SYSTEMS

Conventional colour video systems have been used to

good effect for precision colour measurement where colour differences are larger than those employed in printing [6–8], and also for pre-press [9]. Often in machine vision, the RGB system of representing colour is used, whereby colour is reconstructed from (and represented by) a combination of red, green and blue light. Values are assigned to each colour for storage, e.g. in the range 0–255 for an 8 bit image. In 1931, the Commission Internationale de l’Eclairage (CIE) developed a device-independent colour model based on human perception. The CIE XYZ model, as it is known, defines three primaries called *X*, *Y* and *Z* that can be combined to match any colour that humans see. The conventional RGB system suffers from two shortcomings. Firstly, the conversion of colour information from an RGB system to Cielab [2] XYZ tristimulus values is arbitrary, and many colour data are lost since the RGB colour space cannot map all visible colour. The other shortcoming of RGB-based colour video systems is that quantization produced by analogue-to-digital conversion often exceeds 1 ΔE for 8 and 10 bit systems. Colorimeters, while often useful for demanding applications [10], were found to be too unstable in practice for our purposes. High-resolution print imaging has been achieved using a flat-bed scanner [11] but this method is unsuitable for on-line measurement. The approach therefore taken was to utilize a non-contact spectrophotometer, called the Inspector, in conjunction with a conventional area-scan progressive scan camera [12].

3 COLOUR SPACE CONVERSION

Colour space conversion using standardized mathematical methods is carried out and these methods are described as follows. The CIE tristimulus values of a colour stimulus may be obtained by multiplying the colour stimulus function $\varphi(\lambda)$:

$$X = k \int_{\lambda} \varphi(\lambda) \bar{x}(\lambda) d\lambda \quad (1)$$

$$Y = k \int_{\lambda} \varphi(\lambda) \bar{y}(\lambda) d\lambda \quad (2)$$

$$Z = k \int_{\lambda} \varphi(\lambda) \bar{z}(\lambda) d\lambda \quad (3)$$

where

$$k = \frac{100}{\int_{\lambda} S(\lambda) \bar{y}(\lambda) d\lambda} \quad (4)$$

In order to convert from the XYZ to the *Lab* system the following standard equations are applied, a full description of which (including constants) has been provided in

reference [1]:

$$L = 116 \left(\frac{Y}{Y_n} \right)^{1/3} \times 16 \quad (5)$$

$$a = 500 \left(\frac{X}{X_n} \right)^{1/3} \times \left(\frac{Y}{Y_n} \right)^{1/3} \quad (6)$$

$$b = 200 \left(\frac{Y}{Y_n} \right)^{1/3} \times \left(\frac{Z}{Z_n} \right)^{1/3} \quad (7)$$

When

$$\left(\frac{X}{X_n}, \frac{Y}{Y_n}, \frac{Z}{Z_n} \right) \leq 0.008856$$

the normal equations in (6) and (7) are replaced by the modified formulae

$$a = 500 \left[f \left(\frac{X}{X_n} \right) \times f \left(\frac{Y}{Y_n} \right) \right] \quad (8)$$

$$b = 200 \left[f \left(\frac{Y}{Y_n} \right) \times f \left(\frac{Z}{Z_n} \right) \right] \quad (9)$$

where

$$f \left(\frac{X}{X_n} \right) = 7.787 \left(\frac{X}{X_n} \right) + \frac{16}{116}, \quad \left(\frac{X}{X_n} \right) \leq 0.008856 \quad (10)$$

$$f \left(\frac{Y}{Y_n} \right) = \left(\frac{Y}{Y_n} \right)^{1/3}, \quad \left(\frac{Y}{Y_n} \right) > 0.008856 \quad (11)$$

$$f \left(\frac{Y}{Y_n} \right) = 7.787 \left(\frac{Y}{Y_n} \right) + \frac{16}{116}, \quad \left(\frac{Y}{Y_n} \right) \leq 0.008856 \quad (12)$$

$$f \left(\frac{Z}{Z_n} \right) = \left(\frac{Z}{Z_n} \right)^{1/3}, \quad \left(\frac{Z}{Z_n} \right) > 0.008856 \quad (13)$$

$$f \left(\frac{Z}{Z_n} \right) = 7.787 \left(\frac{Z}{Z_n} \right) + \frac{16}{116}, \quad \left(\frac{Z}{Z_n} \right) \leq 0.008856 \quad (14)$$

To determine the absolute difference between two colours in the *Lab* colour space the equation [1]

$$\Delta E = \sqrt{(L_1 \times L_2)^2 + (a_1 \times a_2)^2 + (b_1 \times b_2)^2} \quad (15)$$

is used.

4 APPARATUS

Figure 1 shows the layout of the image grabbing apparatus, whereby the colour sample is converted to spectral data by the *Imspector*, the resultant image being captured by a conventional monochrome area scan camera. Dot features are captured with a similar camera. A personal computer (PC)-based frame grabber is used for image capture. Colour inspection and dot feature inspection components are arranged such that the same section of web is examined. The fibre-optic light guide carries an optical cable to deliver illumination from a xenon flash. In order to provide the knowledge-based system (KBS) with sufficient information to make judgements about print quality and the state of principal process variables, the following measurement strategy is adopted.

5 SOFTWARE: SPECTRAL IMAGING

Software has been developed for print analyses [13] to examine for flaws, and to examine spectral samples off line [14]. What was required for this experimentation was a spectral imaging package which could acquire the spectral images from a frame grabber on line, in

Fig. 1 Imaging apparatus

order to determine print quality. This software would need to be fully automatic, and completely stable in operation, such that manual intervention would not be necessary in an environment considered harsh for computing equipment. Rapid software prototyping was achievable in Matlab[®] (high-level language) and Simulink (graphical programming interface for Matlab[®]). Software development becomes easier than with lower level languages such as C; yet the developed software can be compiled to C and eventually as a binary executable. This is then ported as a dynamic link library to the Wit image-processing environment. C code generation is automatic with the proviso that glue code is sometimes needed to interface Matlab[®] to system hardware, in conjunction with manufacturers' libraries [15]. This approach combines the power of a high-level language with the input-output capabilities of C such that a system may be developed which can perform image processing and print machine monitoring without spending excessive time coding every mathematical function in C. This approach also makes it easier to modify code in future, e.g. to allow for multiple imaging set-ups with several cameras. Input-output functions are already available for Matlab[®] from a number of sources in conjunction with data acquisition hardware. These systems are expensive, however, due in part to their limited market, expense of development and

general-purpose nature. The leaner special-purpose code thus developed can perform satisfactorily for system monitoring at web speeds. The code has proved reliable over long periods. In addition, the software developed allows fully automatic sampling from the printed web and may be left running continuously with no upper time limit other than the operational life of the PC. Reference to the equations shown in section 2 will reveal the internal workings of the colour space conversion software elements.

6 SOFTWARE: DOT FEATURES

Figure 2 shows the basic Wit Igraph used for dot feature analysis. The more complicated example used in practice features control loops to time external activities such as flash synchronization, and the simplified version is included here for clarity, containing all essential elements. Firstly, the image is acquired using the Acquire operator and is then automatically thresholded to produce a binary image. The threshold level is determined by the mean grey scale level of the entire image and, in practice, has been found to be very stable in operation. Noise is removed by thresholding blob feature information, such that specks below a minimum size are ignored. The resultant image is then added to the original

Fig. 2 Dot feature recognition Igraph

Fig. 3 Parameters for post-processing

raw image and occupies the red channel of an RGB image such that blob outlines are clearly visualized, as an indicator that the software is working correctly.

7 PORTING OF RESULTS TO THE KNOWLEDGE-BASED SYSTEM

The imaging system has been designed to interface with a KBS, whose design has been described previously [16], which logs process parameters such as dot features, web speed and ink viscosity, in order to evaluate process health. A full description of the KBS learning capability and user interface is not provided here, since it is the intention of this paper to show that the imaging data are provided in such a form, and with such a degree of robustness, that they may be used by a post-processing system. In this case the KBS is able to make recommendations to an operator to produce acceptable quality print, while visual colour drift is not yet detectable by a human being, consequently avoiding potential scrap and wastage.

After acquiring data from the imaging system, the KBS analyses colour drifts and dot feature drifts (Fig. 3). If any of these drifts goes beyond tolerance, the KBS will conduct the following diagnosis. When colour drift at 100 per cent tone is found beyond

tolerance, which is reckoned as a problem of ink colour, the KBS will instruct the user how to change the ink viscosity. However, when colour drift at 50 per cent tone and/or dot feature drifts are found beyond tolerances, the KBS will provide suggestions for the adjustment of process variables such as impression pressure. Implementation of Table 1 for use in a fuzzy system has been described in reference [16], whereby dot feature parameters may be related to process parameters of impression pressure, web speed and viscosity. Examination of the tone blocks printed at the edge of the web show that examination of a combination of tone levels of 25 and 50 per cent works reliably for identification of print defects, primarily since distinct dots are visible at 25 per cent, allowing the imaging system to measure features such as dot size accurately. Colour data ported to the KBS is somewhat simpler and is described in Table 2.

8 RESULTS: SPECTRAL SYSTEM

The spectral image is shown in the top left corner of Fig. 4. Currently an average of five samples is taken (to reduce noise) towards the centre of the image (to reduce the effects of chromatic aberration towards the edges of the front end optics), and the resultant averaged

Table 1 Dot feature parameters and description

Feature	Object	Definition
Drag out	Dot (25% tone level) dx and $dy < 0.34$ mm	dx/dy
Haze	Points with grey-scale lower than average (25% tone level)	$\frac{G \times G_{\text{substrate}}}{G_{\text{ink}} \times G_{\text{substrate}}}$
White hole size	Closed small shape with grey scales of all internal points lower than average (25% tone level)	dx and $dy < 0.34$ mm
Boundary roughness	Dot (25% tone level)	Percentage of image to fall through 20×20 pixel convolution filter
Blotchiness	$dx < 1$ mm and $dy < 0.34$ mm <i>or</i> 1 mm $> dx > 0.34$ mm and $dy < 0.34$ mm	$\max[\text{area or } (dx dy)/2]$
Rivering	Large river-like shapes (50% tone level) $dx > 1$ mm and $dy > 0.34$ mm	$\max[\text{area or } (dx dy)/2]$
Streaking	Long lighter-darker lines, dashed or continued (25% tone level); for continued dark lines, $dx > 1$ mm and $dy < 0.34$ mm	Length of dot tail or amount of scratched ink (by visual judgement)

Table 2 Colour data ported to the KBS

Feature	Object	Definition
Substrate white reference	Zero tone (paper)	CIE L^* , a^* , b^* coordinates
Substrate-ink interaction	50% tone	CIE L^* , a^* , b^* coordinates
Ink colour	100% tone	CIE L^* , a^* , b^* coordinates

Fig. 4 Spectral imaging system output screen (test mode)

image 'slice' is ported from the image grabbing code. In each tristimulus plot, curves are represented as follows. The input spectral curve is shown, together with the tristimulus curve. The crossing points show the effect of convoluting the arrays containing the tristimulus and the original spectrum. The area under these curves is found using piecewise integration to find values of X , Y and Z for the image.

A statistical analysis of the experimental results for colour drift and device sensitivity is shown later in Table 4. The highest standard deviation (SD) for examination of the same colour is obtained with the Gretag SPM 50. This could be accounted for by the 0–45° illumination method, which is less stable to surface geometry than an integrating sphere. A lower SD value is achieved using the Inspector, which averages over spectra obtained from five sample points during each image grab, making colour acquisition more stable. The use of an integrating sphere gives a marginally more stable result for the Datacolor Microflash than for the Gretag SPM 50.

When examining the gain of the devices when subjected to natural variations in the printing process, although the natural SD of the device is acknowledged, a difference in the results for colour drift measurement is seen for each

device, measuring the same samples. An indication of the sensitivity of each device to colour variations (also describable as gain in ΔE) between sample pairs may thus be provided. This enables us to look further at the performance of the Inspector. The machine trials thus undertaken showed that the Inspector has the lowest apparent gain for natural deviation in the printed colour, and the Datacolor microflash has the largest.

It must be remembered that absolutes are not compared; i.e. no spectrophotometer can provide a concrete datum for colour measurement against a standard reference in, for example, the same way as a voltmeter or micrometer. However, all systems are measuring within the same colour space and with the same method of processing spectral data, so that relative performance can be compared. The natural background noise of each device limits sensitivity to colour change, and the ratio of the natural variation in the printing process to this background noise can be used to determine useful colour drift gain for each device (for comparative purposes only, these results cannot be viewed in isolation and are not applicable to arbitrary points in the colour space). As can be seen from Table 3, the best signal-to-noise performance is achieved using the Datacolor microflash, with the Inspector's performance

Table 3 Relative spectrophotometer performance

	Natural SD for constant-colour ΔL^* > 50 samples (background noise)	SD for 100% tone blocks, stable printing machine trial >30 m sample	Signal-to-noise ratio
Gretag SPM50	0.1349	0.2695	1.99:1
Inspector	0.0409	0.1694	4.15:1
Datacolor microflash	0.1170	0.5270	4.79:1

falling closer to that of the microflash than the Gretag SPM-50. This is due to the low internal drift of the Inspector, making it more stable than the integrating sphere device. By placing the performance of the Inspector between two industry standard devices it can be seen that the colour measurement system developed herein is not only of adequate performance to provide data drive for the KBS but also a potential competitor to conventional spectrophotometers in terms of performance.

9 RESULTS: DOT FEATURE ANALYSIS

The dot feature analysis system has been tested for robustness with regard to varying web speeds and the addition of stray light elements. The dot measurement analysis system has been proven to be robust in both cases, with no measurable difference in dot elongation between a stationary sample and a sample passing beneath the camera at 900 mm/s. The inclusion of almost double illumination intensity produced less than 0.5 per cent error in dot feature measurement with regard to dot size, in pixels. This suggests strongly that the use of an adaptive thresholding algorithm using the mean image grey level as shown in Fig. 2 is a robust solution.

The following figures show typical dot features produced as a result of printing defects. In practice, some 200 dots are recognized and labelled to provide a representative sample. Images displayed here feature a reduced dot count but show all the main dot features

for print defects which must be recognized by the system. Figure 5 shows a relatively clean print with few defects. A print produced by such dots is deemed acceptable by the manufacturer. Figure 6 shows 'white holes'—an area of printed dots where some blockage of the printing cells which carry the ink is taking place. While the dots produced may not affect print quality to any noticeable extent, extrapolation of these features leads to a drop in print coverage, which must be detected. The effect shown in Fig. 7 is known as rivering and is a defect caused by ink flow across the paper from one gravure cell to another. Boundary roughness, where the dots are not printed cleanly, is shown in Fig. 8. Blotchiness is an exaggerated condition, often due to a decrease in the ink viscosity which occurs less often, but must be detectable and is illustrated in Fig. 9. Streaking is

Fig. 6 Hole size **Fig. 5** Good features **Fig. 7** Dot size example (see Fig. 3 for annotation)

Fig. 8 Boundary roughness

Fig. 10 Streaking example

Fig. 9 Blotchiness

where elongated dots begin to connect and is shown in Fig. 10. All the above features must be numerically represented, although indirect representation is acceptable, in order to control the printing process.

Table 4 represents the expected output from the blob feature identification software, using the image shown in Fig. 10 as the reference sample. The number of positive or negative symbols shown denotes the magnitude of the expected increase or decrease in software output variable value. The column headings of Table 4 can be explained as follows. The mean pixels per blob is the total number of image pixels contained within each printed dot. The mean blob D_x and mean blob D_y are the mean X and Y axis sizes respectively of a sample of

around 200 blobs; the white hole is the percentage of image pixels which represent a small unprinted area encircled by a printed dot. The HF content is the amount of the image which may pass through a high-pass convolution filter, in order to reveal the presence of boundary roughness. Isolating each dot and examining the grey levels of the substrate between is used to detect ink bleed-through, a good indicator of a non-clean print. Unique values, and combinations of values, are produced for each processed print defect.

Table 5 shows the actual output from the image-processing software. Correlation between expected results, based on manual viewing and the software output, is very good and acceptable for the industrial application.

10 RESULTS: UTILIZING IMAGING DATA FOR PROCESS CONTROL

A series of trials were carried out on a Cobden Chadwick gravure press, located at Englewood Limited, as shown in Fig. 11. A series of master samples were taken, and then process variables were altered to introduce process error. The KBS system was then used to guide the operator by making suggestions for process setting adjustments. The aim of these trials was to see whether the system was able to detect print faults and offer recommendations to the operator to alter process settings, in order to return print quality to normal. It is

Table 4 Expected results from imaging software (N/A, not applicable)

Sample or feature	Mean pixels per blob	Mean blob D_x	Mean blob D_y	White hole	HF content	Interdot grey
Hole size	N/A	N/A	N/A	+	N/A	N/A
Dot size	++	++	++	+	N/A	N/A
Boundary roughness	N/A	N/A	N/A	++	+++	xx
Blotchiness	++	N/A	N/A	+	++	xxx
Streaking	+	++	+	+	+	x

Table 5 Output from dot feature analysis software for typical print defects

Sample or feature	Mean pixels per blob	Mean blob D_x	Mean blob D_y	White hole	HF content	Interdot grey
Good	2138.29	61.4	57.7	0	0.0134	96.4
Hole size	2400.50	72.0	64.5	44	0.012	99.9
Dot size	4885.55	93.2	127.0	191	0.018	83.0
Boundary roughness	3224.86	75.7	80.4	1801	0.026	77.3
Blotchiness	3237.13	76.9	74.8	535	0.022	74.5
Streaking	2797.40	72.6	72.2	232	0.017	86.7

Fig. 11 Cobden Chadwick gravure press

important to remember that the data link between the machine and the KBS recommendations is based upon imaging data; thus viscosity and impression pressure, which may not be accurately measured, are inferred from imaging data. A summary of adjustment history results from a typical trial is shown in Table 6.

11 DISCUSSION

Tests were carried out using a non-contact spectrophotometer-type device, commercially available (1999) called the 'Inspector'. These tests suggested that colour resolution was very good and that such a system could perform well at web speeds, the technology for monochrome machine vision being well established. The idea of an approach to imaging through use of a non-contact spectrophotometer has been reinforced since this experimental work was carried out [16], since colour resolution for colour cameras is widely seen as a subject for further development within industry and academia, such that the current state of the art in colour videos is

insufficient for the present purposes. While slightly less sensitive to colour drift than a hand-held spectrophotometer, the Inspector has much lower internal noise levels, producing a more stable measuring device.

The dot feature analysis system has been found to be very robust and is capable of measuring dot features from a moving image with minimal error. Thus a system is provided which may be used in future to ascertain whether dot feature characteristics may be used as a comprehensive indicator of process health. The dot feature detection system shows changes in numerical output values which are clearly relatable to specific print defects. Using ΔE as a reference for comparison, the maximum useful precision obtainable using this method is improved by a factor of more than 4 when compared with conventional 10 bit RGB video.

The testing of the integrated system gives an adjustment history which shows that, by following the suggestions made by the KBS, process adjustments can be made to return print quality to an equivalent level as produced by an original master sample, before print drift is detectable by the human eye.

Table 6 Process adjustment history (N/A, not applicable)

Master sample number	Speed (m/min)	Impression pressure (turns)	Viscosity (Foord)	Suggestion to user by KBS	Notes
1	123.88	3	15.5	N/A	Master sample
	92.71	3	15.5	Increase speed	
	111.46	3	15.5	Increase speed	
	123.07	1	15.5	Increase pressure	
	122.83	3	15.5	Increase speed	
	129.32	3	15.5	None: sample = master	
2	124.12	3	15	N/A	Master sample
	124.12	4	15	Reduce pressure	
	124.12	3	15	Reduce pressure	
	124.12	2.5	15	None: sample = master	
3	122.97	3	20	N/A	Master
	124.66	3	19	Increase viscosity	
	125.05	3	20	Reduce speed	
	118.35	3	20	None: sample = master	

12 CONCLUSIONS

Experiments were carried out in image grabbing, image processing and colour space conversion. A system has been developed and tested which can infer printing process variables by analysing images of the tone blocks which exist on the edge of the printed web. Gravure dot features some 80 µm in size are measured at full production speeds of 2 m/s, in conjunction with a non-contact spectral imaging device whose ability to measure colour drift is comparable with contact-based (static sample) devices. The KBS is able to interpret the resultant image data and to make suggestions for machine settings to the operator, ensuring consistency of the printed product.

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