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HALFTONE DOTS SEGMENTATION IN MULTICOLOUR PRINTING

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In order to evaluate print characteristics from the samples of the printing sheets, the segmentation of halftone dots printed with process inks has to be done. Accuracy of the segmentation process influences significantly the following evaluation of print characteristics. This paper describes a suitable and verified method to achieve this aim. The segmentation method is based in the first step on the separation of individual process colours included in the print sample. The result of separation process is the monochromatic image, which is further processed by the threshold segmentation method with optimization of the threshold value.

Introduction

Colour images are printed using the four process inks — yellow (Y), magenta (M), cyan (C) and black (K). In ideal subtractive colour behaviour, each of the primary colours C, M, Y, would subtract one third of the spectrum. The black is added, because the black colour subtractively mixed from C, M and Y is never really black as such. In printing processes, continuous tone originals are reproduced by the use of the halftone screen. The result of this technology is printing various sizes of halftone dots. In various printing technologies there are many steps between the original and the final print product. In each of these processing steps the size and shape of halftone dots are changed and in consequence the prints characteristics as the optical densities, hue, brightness and saturation of colours are changed as well. An image analysis method can be used to measure and evaluate these parameters and then to control the quality of colour reproduction in printing process.

The benefits of the image analysis method are:

- the high speed of the scanning and image recording bymeans of the CCD camera
- the possibility to correct possible defects by the method of pre-processing of the scanned image
- the simultaneous scanning of the colour characteristics and geometrical parameters of printed samples

The image analysis method developed for the measuring of print characteristics with a colour CCD camera enables scanning print samples not only from the special control strip printed alongside the sheet, but from the suitable part of printed image too. The high speed of print sample scanning and evaluation of print parameters enable measuring and automatic control in real time.

Characteristics of the Print

The optical density of a colour ink layer is calculated using the following formula

$$D = \log\frac{1}{R} = \log\frac{I_0}{I} \qquad (1)$$

where R is the reflectance factor, I_0 is the intensity of the light incident on the sample surface, and I is the intensity of the reflected light.

The colour components r, g, b detected by CCD sensor correspond with optical densities of process colours in the following way

- the component $r_{i,j}$ determines the density of the cyan pixel i, j
- the component $g_{i,j}$ determines the density of the magenta pixel i, j
- the component $b_{i,j}$ determines the density of the yellow pixel i, j
- the value $(r_{i,j} + g_{i,j} + b_{i,j})/3$ determines the density of the black pixel i, j

Then optical densities evaluated from this components can be calculated using the following equations [6]:

the optical density of cyan

$$D_c = \log\frac{1}{R_c}, \qquad R_c = \frac{\sum_{i,j} r_{i,j}}{Nw} \tag{2}$$

the optical density of magenta

$$D_m = \log\frac{1}{R_m}, \qquad R_m = \frac{\sum_{i,j} g_{i,j}}{Nw} \tag{3}$$

and the optical density of yellow

$$D_y = \log\frac{1}{R_y}, \qquad R_y = \frac{\sum_{i,j} b_{i,j}}{Nw} \tag{4}$$

where R_c, R_m, R_y are reflectances of cyan, magenta and yellow, N is the number of pixels in the measured area and w is an average value of reflected light from the white sample (e.g. printing paper).

There is linear correlation between these values and values which are evaluated by the conventional densitometric measurement [1].

The value of dot area in halftone print [2,3] can be determined as the geometrical effective ink surface coverage F_G

$$F_G = \frac{S_p}{S_p + S_u} \times 100\ \% \tag{5}$$

where S_p is printed area and S_u unprinted area of the halftone print sample.

The densitometric dot area F_D can be calculated using the Murray-Davies formula from the measurement values of solid (D_S) and halftone densities (D_A)

$$F_D = \frac{1 - 10^{-D_A}}{1 - 10^{-D_S}} \times 100\,\% \qquad (6)$$

The ink trapping describes the ability of an ink to adhere to a surface onto which it is being printed. This surface is the substrate (usually paper) for the first ink printed, but subsequent inks may be printed completely onto the substrate and partially onto the ink film. The ink trapping is calculated from the solid density values for every individual colour in the solid fields. The ink trapping calculated with the following formulae indicates which percentage of an ink is superimposed onto another. The value is given relative to that of an isolated ink printed on the paper whose trapping is set to 100% [2,3]. For two-colour superimposition

$$T_l = \frac{D_{12} - D_1}{D_2} \times 100\,\% \qquad (7)$$

where D_1 is the ink density of the colour printed first, D_2 is the density of the colour printed second and D_{12} is the ink density for the superimposition of both colours. All ink densities must be measured with a filter which is complementary to the second printed colour.

The ink trapping determines the quality of the overprint of one process colour by another. The trapping value less then 100 % causes a shift of the hue with respect to the theoretical value. To evaluate the quality of process colour overprints the value of the colour difference can be used. The quantity ΔE of the colour space CIELAB is suitable for this purpose.

$$\Delta E = \sqrt{(L^* - L_t^*)^2 + (a^* - a_t^*)^2 + (b^* - b_t^*)^2} \qquad (8)$$

where L^*, a^*, b^* are colour co-ordinates of real overprints, L_t^*, a_t^*, b_t^* are colour coordinates of the theoretical overprints.

To calculate these parameters from multicolour print sample, the segmentation of screen dots of individual process colours and there overprints has to be done. In the case of print with four process inks, we can obtain some of eight various segmented regions in accordance with the content of colours in the processed sample These regions can be some of colours C, M, Y, K, C + M, C + Y, M + Y and C + M + Y.

Algorithm of Segmentation

The method of screen dots segmentation of individual process colours C, M, Y, K (Cyan, Magenta, Yellow, Black) from colour samples is described in this paper. The precise segmentation of screen dots of individual process colours is very important for the calculation of printing parameters e.g. optical density, halftone value and ink trapping. The RGB colour model and HSB (hue, saturation, brightness) colour model were used for the purpose of screen dots segmentation. The segmentation procedure consists of two steps [6]. In the first step the separation of individual process colours is performed from the colour sample. In the second step is performed the segmentation of screen dots from monochromatic images, obtained by the separation.

Process of the separation is based on the fact, that primary densities (e.g. cyan in cyan, blue and green or yellow in yellow, green and red) are greater than secondary densities (e.g. yellow in magenta, cyan and blue) [6]. This fact is presented in Fig. 1.

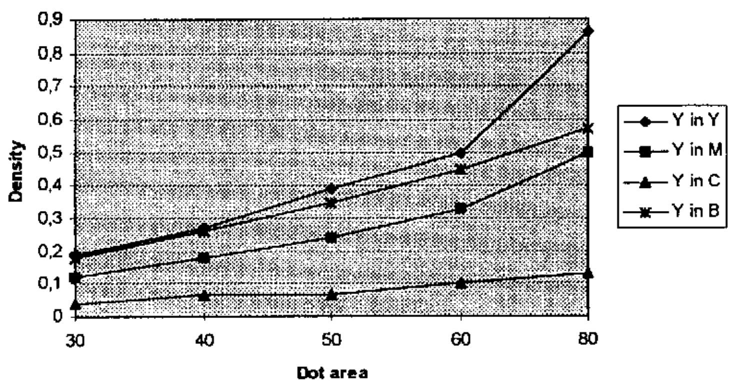

Fig. 1 Primary and secondary densities

In the case of small differences between primary and secondary densities in the print samples, the brightness transformations of separating process colour in the suitable interval of hue can be performed before separation procedure. The value of this interval is obtained by calculation of statistical mean value and dispersion of quantity hue of process colours from calibration mark, which comprises the fields of process inks and their overprints. For example the contrast increase of hue in the interval magenta-red has to be done before separation of yellow screen dots. A successful separation also depends on the choice of suitable print samples. It is easier to process a two-colour sample than a four-colour sample.

The process of segmentation is based on the threshold segmentation method

[4]. The threshold value is usually calculated from the brightness histogram. Histograms obtained from monochromatic separations of the colour samples have usually two or three peaks according to the number of colours included in the multicolour sample. The first peak corresponds with primary colours, the second with secondary colours and the third with the white background [6]. The suitable threshold value is between the first and the second peak of brightness histogram [4]. The optimum threshold value can be evaluated from this brightness histograms using information of contrast on the halftone dots borders.

The segmentation by the threshold value computed in the middle between the first and the second histogram peaks is not accurate enough. The calculation of the optimum threshold value improves the accuracy of the segmentation. For sufficiently accurate segmentation it is important to know which level of brightness corresponds with the halftone dot border. Assuming, that the border of halftone dot is in the center of the dot edge, we can assume the maximum of contrast on the brightness level in the center of the dot edge The optimizing method is based on this fact.

The contrast in the border dot [5]

$$C(a, b) = I(a) - I(b) \tag{9}$$

where a, b are the neighbouring dots on the region border, I(a), I(b) are the intensities in a, b.

The average contrast on the dots borders gained by thresholding with the threshold value T [5]

$$C_{av}(T) = \frac{C(T)}{N(T)} \tag{10}$$

where $N(T)$ is number of all halftone dots on the border and $C(T)$ is the sum of contrasts of these dots.

The iteration procedure of the optimum threshold evaluation is performed by the segmentation of halftone dots with gradually growing values of threshold between the first and second peaks of the brightness histogram. Then the halftone dots borders of each segmented image are calculated, and finally the average contrast at these borders. The threshold value which corresponds with the maximum average contrast is the optimum threshold value. Figure 2 shows the table and the graph of average contrast as a function of threshold level for the Cyan separation. The method of threshold optimizing by calculation of maximal contrast on the halftone dots border is suitable first of all for halftone dots with sharp edges.

Treshold	90	95	100	105	108	109	110
Contrast	271.2	273.8	276.4	276.3	277.1	276.8	277.6
Treshold	111	112	115	120	125	130	
Contrast	277.3	276.6	275.9	271.4	269	262.8	

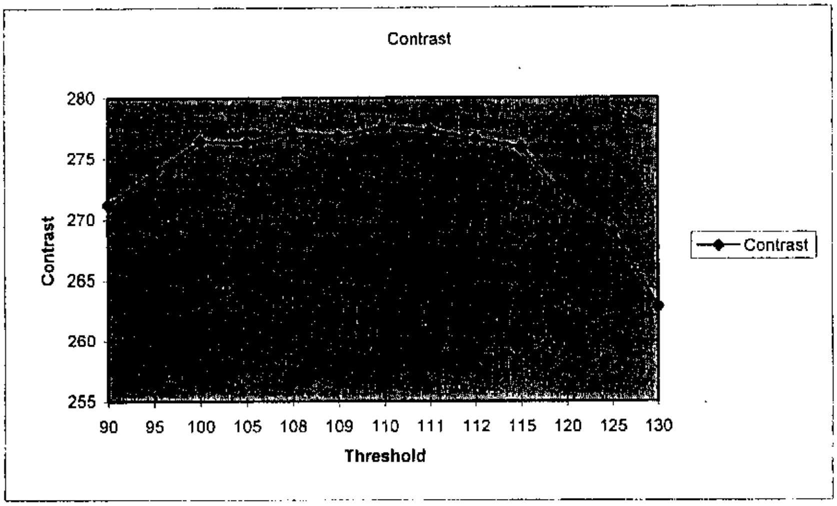

Fig. 2 Average contrast of cyan sample separation

Results of Segmentation

The image analysis program package of print samples was developed for the purpose of calculation of printing parameters. A very important part of this package is the process of screen dots segmentation. After the separation of process colours in the print sample we obtain monochromatic images. The number of these images corresponds with the number of process inks included in the print sample. In every image the lowest value of brightness corresponds the with primary process colours separated. Application of the described algorithm of segmentation by the threshold values between the first and the second peaks of brightness histograms provides the segmented regions of primary process colours. Figure3 gives the result of the separation and segmentation of the magenta screen dots regions from a three-colour print sample.

For the purpose of print characteristics evaluation in overprints it is necessary to separate the overprint regions of C–M, C–Y, M–Y, C–M–Y from those of pri-

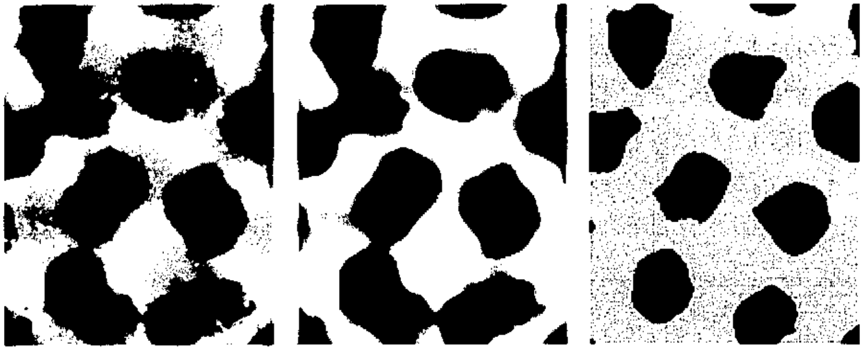

Fig. 3 Separation and segmentation of magenta screen dots

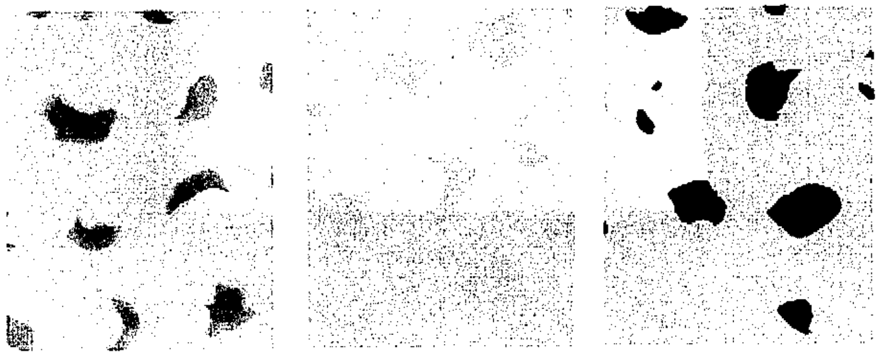

Fig. 4 Segmentations of cyan, yellow and blue

mary colours. This can be achieved by logical operations because regions of overprints are overlaps of primary colours regions obtained by the previous separation method. This fact is used in an algorithm that separates overprints from regions of primary colours. The final result of segmentation processing is a set of images with regions of clean process colours and with regions of overprints.

The images of these segmented regions are then used to mask the original scanned image to get this regions before transformation operations. This final image can be used to calculation of basic print characteristics presented above. In Fig. 4 there are presented images of masked cyan, yellow and blue (overprint C–M) regions from a three-colour print sample.

Accuracy of the segmentation can be defined as the size difference between the real objects in the image and the segmented objects. In the case of screen dots it is difficult to say which size of the real object is the accurate size because of various values of printing dots edges in one print sample. The quantity halftone value was used to compare the method of image analysis and densitometer measure-

Colour	Yelllow	Magenta	Cyan	Yelllow	Magenta	Cyan
Refer. Value	20	30	40	50	60	70
Dens. Value	29.5	41.5	50.1	66.3	76.8	82.1
ImAnal. Value	21.8	33.7	39.1	52.9	66.5	74.6

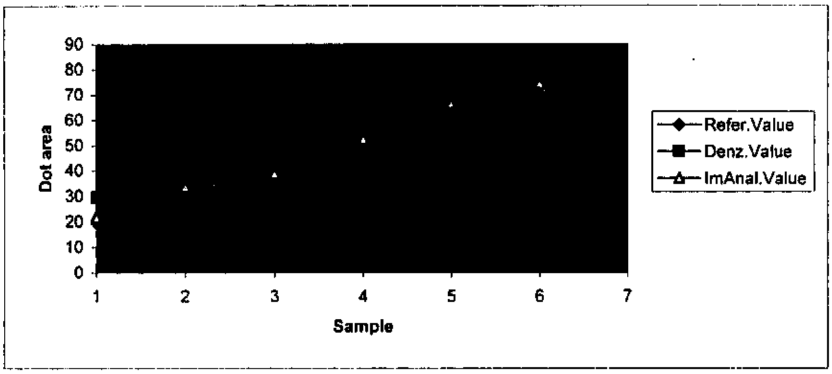

Fig. 5 Comparison of the densitometric and image analysis dot area

ment to characterise the segmentation accuracy. We scanned several sets of one-colour halftone print samples from the colour catalogue of the Linotype-Hell Comp. The halftone values were measured an evaluated by the densitometric method and by the image analysis method. Correlation factors between the reference values, densitometric values and image analysis values were greater then 0.99. Graphic results for one set of samples are presented in Fig. 5.

Conclusion

Masked images are used as input data for the following evaluation of the printing characteristics. These are the densities of clean process colour inside the halftone dots and the trapping inside overprints, which characterise the quality of overprint of one process colour by another. The dot area value can be evaluated directly from the segmented regions before their dividing into clean process colours C, M, Y and overprints C–M, C–Y, M–Y and C–M–Y.

Many one-colour, two-colour or three-colour print samples have been processed by the method described in this paper. Basic printing parameters have been calculated by the method of image analysis.A good correlation was achieved when comparing the results with those of densitometry in the cases of density, dot area and trapping.

The method presented in this paper is suitable above all for print technologies with sharper halftone dots and consequently with small edges. This is e.g. the case of flexoprint technology. Technologies with non-direct print (e.g. offset) produce halftone dots with larger edges and it is difficult to evaluate the optimum threshold value. Other methods are suitable in these cases for more precise segmentation e.g. regions growing.

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