Characterisation of the *n*-colour printing process using the spot colour overprint model

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Abstract: This paper is aimed at reproducing the solid spot colours using the *n*-colour separation. A simplified numerical method, called as the spot colour overprint (SCOP) model, was used for characterising the *n*-colour printing process. This model was originally developed for estimating the spot colour overprints. It was extended to be used as a generic forward characterisation model for the *n*-colour printing process. The inverse printer model based on the look-up table was implemented to obtain the colour separation for *n*-colour printing process. Finally the real-world spot colours were reproduced using 7-colour separation on lithographic offset printing process. The colours printed with 7 inks were compared against the original spot colours to evaluate the accuracy. The results show good accuracy with the mean CIEDE2000 value between the target colours and the printed colours of 2.06. The proposed method can be used successfully to reproduce the spot colours, which can potentially save significant time and cost in the printing and packaging industry.

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1. Introduction

Colour separation is the process by which an original colour image is decomposed into individual single-colour components for printing using primary inks, for example, cyan, magenta, yellow and black (CMYK). The *n*-colour printing process uses more than four process inks usually with the intermediate hues like orange, green, violet etc. This increases the colour gamut of a traditional four-colour printing process, but makes it more difficult to obtain the colour separation.

The packaging printing industry traditionally uses CMYK process inks to reproduce photographic images and the spot colours with their own premixed inks to reproduce critical brand information like logos. In contrast, *n*-colour printing uses a fixed ink-set consisting of *n* inks to reproduce all the elements in the given print job using a combination of different overprint tints. The spot colours can be broken down into tints of process channels. This avoids hundreds of special inks, saving storage in the pressroom. It also allows the combination of several print jobs into one job. This project is mainly focussed on the benefit of replacing the solid spot colours and special inks by using the *n*-colour printing process.

Since the invention of the four-colour printing process, various problems related to colour separation and colour fidelity of the CMYK printing process have been studied [1]. Although the conventional process is adequate in most of cases, the colour gamut of typical CMYK inks is restricted as compared with that of display devices. By increasing the number of inks the colour gamut of a printing device can be expanded [2]. The use of additional inks also increases the number of degrees of freedom, thus augmenting the possibility of isomeric matching. Typical *n*-colour printing systems consist of CMYK plus additional intermediate colours such as orange, green, violet, etc. Although adding these inks to the traditional set of CMYK inks increases the attainable colour gamut, the added complexity creates a challenge in generating suitable separations for rendering colour images [3].

The *n*-colour printing process has been explored in several studies before [2–15]. The spectral printer models were evaluated using more than four inks [7–12]. These models were based on the constraints using criteria such as minimising metamerism and increasing colour constancy. Emmel and Hersch [16, 17] introduced new models that describe the light scattering and ink spreading phenomena. They incorporated all physical phenomena into a single model using a mathematical framework based on matrices. Morovic et al [13] proposed a new colour separation method by specifying the relative area coverages of the printer's Neugebauer primaries instead of using the colorant space. This approach gives access to all printable patterns that extend over the Neugebauer Primary area coverage, resulting in a larger gamut.

Although the spectral models have been used for the *n*-colour separations, they are complex and the inversions of the models are computationally expensive. They are based on spectral data, which may not be readily available throughout the pre-press and print production. Hence they cannot be easily integrated in the existing workflow in printing industry. A simpler and more robust solution based on CIELAB or CIEXYZ data is needed that gives effective reproduction of the spot colours.

The spot colour overprint (SCOP) model [18, 19], which is inspired from the Van De Capelle model [7], was proposed to predict the colorimetry of the overprint of spot colours. Main objective was to offer a simple model which can be incorporated within the current ICC and PDF/X workflow. This model was extended to be used as a forward printer characterisation model for the *n*-colour printing process. The paper describes the forward characterisation of the *n*-colour printing process using the SCOP model, the inverse printer characterisation model using look-up table and evaluation of the *n*-colour separation using a set of spot colours.

2. Theory

2.1 The SCOP model

The SCOP model [19] is used to predict colours resulting from combinations of special inks, which includes solid overprints as well as halftone overprints. The assumption made in this method is that at each wavelength the reflectance factor of an overprint approximates the product of the reflectance factors of the two inks measured independently. When this reflectance product is modified using power regression, the approximation is often a good prediction of the actual reflectance. Since CIEXYZ is a linear transform of reflectance, the same approach can be adopted for CIEXYZ tristimulus values.
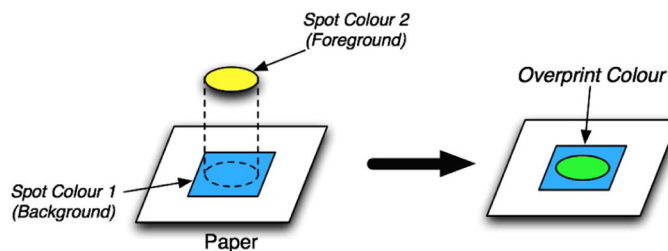

Fig. 1. Spot colour overprint – background and foreground colours.

Suppose we want to print a spot colour over another colour. To predict the resulting colour, we can consider the underlying colour as a background object and the spot colour as a foreground object (Fig. 1). The overprint model assumes that a resulting colour (X, Y, Z) is correlated to the multiplicative function of the background colour (X_b, Y_b, Z_b) and foreground colour (X_f, Y_f, Z_f). Resulting colour (X, Y, Z) is predicted as follows:

$$X = jx\left(X_b X_f\right)^{kx},$$
$$Y = jy\left(Y_b Y_f\right)^{ky}, \tag{1}$$
$$Z = jz\left(Z_b Z_f\right)^{kz}$$

where

$[X_b\ Y_b\ Z_b]$: tristimulus values of the background colour.

$[X_f\ Y_f\ Z_f]$: tristimulus values of the foreground colour.

$[jx\ jy\ jz]$: Scaling factors of the foreground colour.

$[kx\ ky\ kz]$: Exponents of the foreground colour.

The above equation can be used recursively to calculate any colour printed by multiple inks, for example 3-inks, 4-inks and so on. The model coefficients (scaling factors and exponents) are dependent on the foreground colour. There is one set of coefficients per ink and per halftone value interpolated from the measured halftone values, for example 50% and 100%, of the foreground ink colour. They can be calculated from the ink step-wedge chart of the foreground colour. This is explained in detail below.

2.2 Derivation of the model coefficients using the ink step-wedge chart

Each of the three independent component equations in Eq. (1) contains two unknowns, the scaling factor *j* und the exponent *k*. They can be determined by using at least two overprint configurations with known resulting colours (*X, Y, Z* values). This means that information on some overprints must be available. A practical approach is to use overprints on black and on grey. This leads to an ink step-wedge chart. Figure 2 shows an example of ink step-wedge chart with 11 steps including solid and substrate. A separate chart must be printed for each ink that is to be characterised. The tristimulus values (*X, Y, Z*) of each patch must be measured.

The chart provides three overprint configurations for each tint, namely on white, on grey and on black. For each tint, all overprint configurations can be used as resulting colours (*X, Y, Z*) in Eq. (1). The foreground colour is obtained from the tint on the white background. The background colour can be obtained from the 0% configuration, for example, white, grey and black colours. The model coefficients, *j* and *k*, for each tint can be obtained by applying the power regression using Eq. (1). Note that the coefficients pertain to the foreground colour in order to apply them in Eq. (1) sequentially, ink by ink.
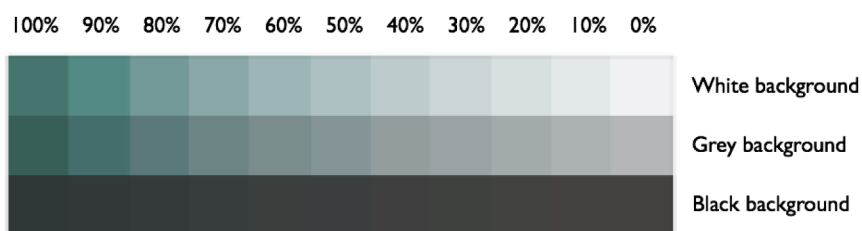

Fig. 2. Ink step-wedge chart.

Implementation of the SCOP model is described fully in [19]. This model can be used for different applications, for example, previewing the spot colour overprints on monitor using pre-media software. Here, the SCOP model is recursively applied to a printing system consisting of *n* inks.

3. Method

3.1 Colorant space division

A printing process with 7 inks was used as a representative of the *n*-colour printing process with the following inks: Cyan, Magenta, Yellow, Black, Orange, Green and Violet. The 7-dimensional colorant space was divided into sectors of 4-inks each as follows: CMYK, OMYK, CGYK and CMVK (Fig. 3).
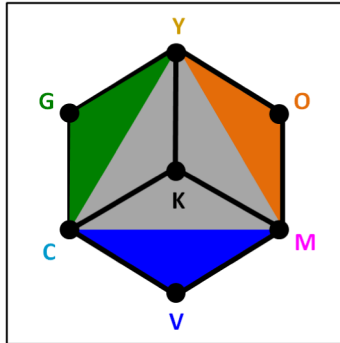

Fig. 3. Four sectors of the CMYKOGV colorant space.

Every sector contains black channel (K) so as to provide a balanced division. In addition to CMYK, three sectors are defined based on the secondary colour as a dominant colour of the sector. For example, OMYK is the orange-sector with orange as a dominant colour, magenta and yellow as a primary colours and black as an achromatic colour. This approach is similar to previous studies [14, 15]. This method can be generalised for any *n*-colour printing process. For example, in case of an 8-colour printing there will be five sub-sets of 4-inks containing black as a common ink and three chromatic inks in each sub-set.

3.2 Printing technologies

Multiple printing technologies were used in this study to implement and evaluate the *n*-colour separations, for example, lithographic offset, flexography and thermal sublimation. The substrate used for the lithographic offset and the thermal sublimation printing was coated gloss paper and that for the flexographic printing was white film. Amplitude modulation (AM) halftone screening was used with 150 lines per inch screen frequencies. The ink lay-down order was Black – Violet – Cyan – Green – Magenta – Orange – Yellow. This was based on reducing the tack order from the first ink to the last.

Unlike the conventional 4-colour printing, the screen angles should be carefully assigned to all inks in the *n*-colour printing. Complementary colours were assigned the same screen angle. The following screen angles were used: Cyan and Orange = 15°, Magenta and Green = 75°, Yellow and Violet = 90° and Black = 45°.

3.3 Calibration

Each printing system was calibrated to adjust its behaviour to known desired conditions. For example, the lithographic offset printing process was calibrated by matching the tone value curves [20]. Tone values for Cyan, Magenta and Yellow were adjusted to achieve the required tone value increase (TVI) targets of "curve A" specified in ISO 12647-2 [21]. Tone values for Black, Orange, Green and Violet were adjusted to achieve the tone value increase (TVI) targets of "curve B" specified in ISO 12647-2 [21]. Similarly for the flexographic printing process the ISO 12647-6 [22] aim values were used with the tone value increase curve for the substrate type 4 (Film/Foil).

3.3 Test charts for evaluating the forward printer characterisation model

For each 4-ink sector, the ECI2002 test chart [23] was generated and printed using the different printing processes. Each test chart contained 1485 colour patches. Each test chart contained the same colorant values (dot areas). For example, in the OMYK chart, all values of cyan (C) ink in the CMYK chart were replaced by orange (O) ink. By combining all ink sectors, there were a total of 5940 colour patches representing the overall 7-colour printing process.

The colour patches in each test chart were measured using an X-Rite i1 Pro 2 spectrophotometer with the following measurement conditions: CIE illuminant D50, CIE 2° standard observer, 45°:0° measurement geometry with a white backing material. A UV absorbing filter fitted to the instrument was used to remove the UV component of the lamp spectral power distribution.

4. Forward printer characterisation

The SCOP model was extended to 4-inks combinations for each ink-sector (Fig. 4) and then to 7-inks combination using four ink-sectors. A modular framework of Matlab functions was developed to implement the model.

The training set used for deriving the model coefficients consists of the following colours: 6 colour patches per primary ink – solid and 50% ink printed on white (plain substrate), grey (50% black) and black (100% black) backgrounds. In addition, the plain substrate, 50% black and 100% black colour patches were measured to represent 0% of inks on white, grey and black backgrounds respectively. A total of 39 colour patches were used as input measurements for the model. Measurements of the tristimulus values of these colour patches were obtained from the ECI2002 test chart to represent the training set. The remaining colour patches from the test chart were used as a test set for evaluating the model accuracy.

For each ink, the tristimulus values of all dot areas were calculated using one-dimensional linear interpolation of the colour measurements from the training set. For example, if we have the measured tristimulus values of the solid (100%) and 50% of cyan ink on white background, we can calculate the tristimulus values of 1%, 2%, …., 98%, 99% cyan by linear interpolation of X, Y and Z values separately. Similarly we can calculate the tristimulus values of all dot areas of each ink for the grey and black backgrounds using the training set. A set of all the tristimulus values were called as 'Ink step-wedge data'.

Since the black ink was printed first, we don't have to calculate the model coefficients for this ink. For each chromatic ink, the model coefficients were calculated using Eq. (1) for the solid, 50% and 0% over three backgrounds using the training set. The model coefficients for the remaining dot areas (1%, 2%, …., 98%, 99%) were calculated by interpolating the known values. We call a set of all coefficients as the 'Coefficients data'.
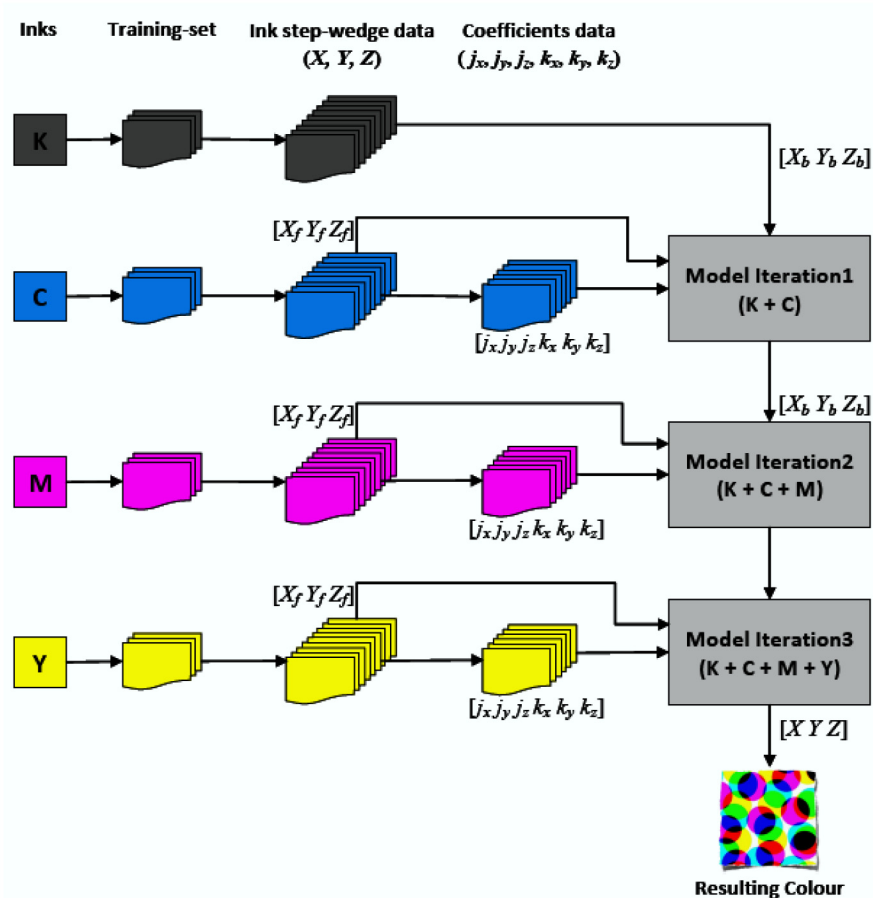
Fig. 4. Implementing the SCOP model to 4-colour printing process.

For each ink-sector, we have a test set of 1485 colorant values for which we want to predict the CIELAB values. We consider the first iteration, for example, cyan printed over black (K + C). For each patch in the test set, the tristimulus values of the background colour and the foreground colour were obtained from the 'Ink step-wedge data' of cyan ink. The model coefficients for the foreground colour were obtained from the 'Coefficients data'. Using these inputs, we applied Eq. (1) to calculate the resulting colour of the first iteration.

The next iteration contains the third ink, for example, magenta ink printed over black and cyan inks (K + C + M). The resulting colours from the first iteration become the background colours. The tristimulus values of the foreground colours of all patches in the test set were obtained from the 'Ink step-wedge data' of magenta ink. Similarly the model coefficients for the foreground colour were obtained from the 'Coefficients data' for magenta ink. The resulting colours of this iteration were calculated using Eq. (1). Finally the last iteration follows the same method described for the previous iteration by adding yellow ink as the foreground colour. This gives the resulting colour of the 4-inks combination (K + C + M + Y).

The above mentioned steps of four iterations were applied for the remaining ink sectors to predict the colours of 1485 patches in each sector. The predicted colours were compared to the colour measurements to calculate the CIEDE2000 colour difference values (see Table 1).

5. Inverse printer characterisation

The inverse printer characterisation provides a colour separation by mapping the device-independent colour to device-dependent colorant values for a given viewing condition. If the forward relationship from colorant values to colour values is defined by a physical printer model then the inversion is possible using analytic or search-based optimisation methods. Due to inherent nonlinearity of the printing process inversion is difficult. Several studies explored the inverse printing characterisation using spectral models [24–28].

For a 3-color process, the inversion is trivial since there is a unique combination of colorants to achieve any given colour. For a 4-colour process, where a black ink is used in addition to chromatic inks, there are many combinations of colorants resulting in the same colour. By dividing the colorant space of *n*-colour process into sectors of 4 inks, the inversion model is applied to 4-colour process of each sector. Figure 5 gives an outline for implementing the inverse printer characterisation for the 7-colour printing process.
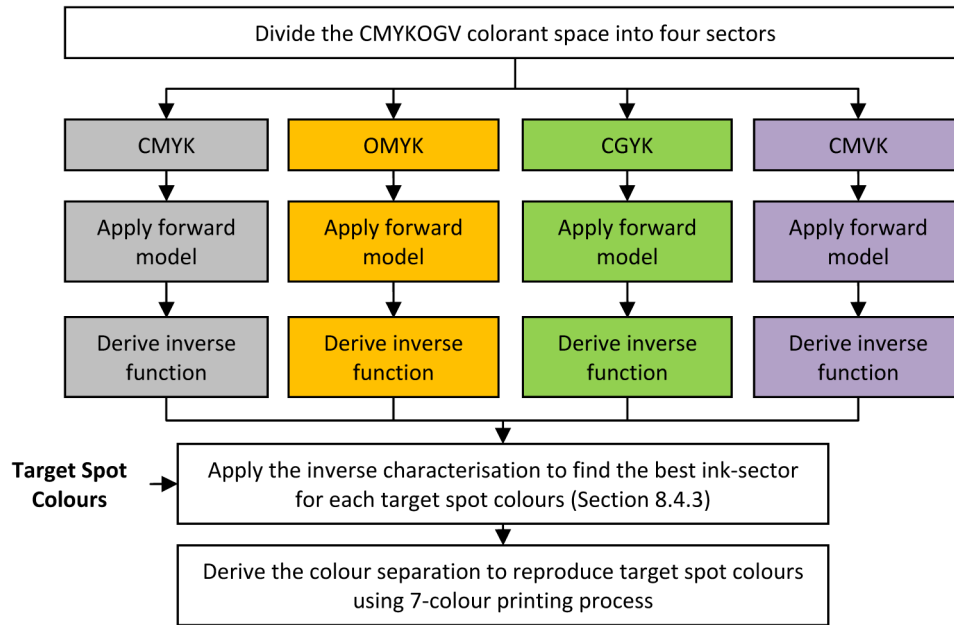
Fig. 5. Implementing the inverse printer model to 7-colour printing process.

5.1 Gamut mapping

Before applying the inverse printer models, gamut mapping was performed. The coordinates lying outside the sector gamut were first mapped to the gamut surface using minimum ΔE clipping method [29]. Each colour was evaluated to check if it is inside the gamut or not. If it is outside the gamut, the nearest coordinate on the gamut boundary was found. The desired colour was replaced by the nearest point on the gamut boundary. This minimises the colour difference between the target colour and the reproduced colour. All colours lying inside the gamut were not affected by the gamut mapping. For reproducing tonal data, overprints and images, this may not be the best strategy. However, the main focus was on reproducing solid spot colours. Hence the minimum ΔE clipping method would provide better results.

5.2 Look-up table

Colour separation can be implemented using a 3-dimensional lookup table (LUT) to map the device-independent colour values to device-dependent colorant values. This method is widely used in many applications including the ICC workflow [30].
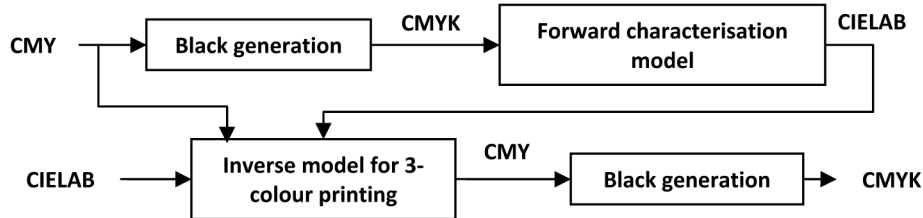
Fig. 6. Inverse characterisation for the 4-colour printing process [24].

Figure 6 illustrates the implementation of the inverse printer characterisation for the 4-colour printing process. The inverse function for the 3-colour printing process is first calculated using the forward characterisation method to obtain colour separation for three chromatic colours. Then the black generation is accomplished to provide the 4-colour separation CMYK.

5.3 Inverse model for 3-colour printing system

Forward SCOP model was used to generate a lookup table of training samples in device-dependent CMY values and corresponding device-independent CIELAB values. The training set consisted of 729 coordinates of a 9-level uniform lookup table. An independent set of 794 samples was used as the test set. This test chart consisting of the test samples was printed and the CIELAB values of all colours were measured using spectrophotometer. These CIELAB values were mapped by using the lookup table to estimate the required CMY values using linear interpolation method.

5.4 Inverse model for 4-colour printing system

For the CMYK inversion, a uniform lookup tables with different nodes were tested. A set of 1485 samples was used as the test set. This test chart was printed using the lithographic offset printing process and the CIELAB values of colours were measured using spectrophotometer. These CIELAB values were mapped to estimate the CMY values by using the lookup table. This inversion is similar to the method described in the previous section (CMY inversion). Linear interpolation method was used to derive the inverse model with 5-level, 9-level and 17-level lookup table sizes.

Next, the black generation and the grey component replacement (GCR) were applied to obtain a unique transform from CMY to CMYK. The estimated device values (CMYK) were mapped through the forward printer model to obtain the CIELAB values. The colour difference values between the final CIELAB values and the original target CIELAB values of 1485 samples were calculated. Finally, the 4-colour inversion model is applied to all ink-sectors to characterise the 7-colour printing process.

5.5. Inverse printer model for 7-colour printing system

Any given colour can be reproduced using a maximum of 4 inks belonging to the corresponding ink-sector. Finding the best sector for the target colour is described in Fig. 7.

First, the forward characterisation is applied to each sector using methods described in the previous section. All sector-gamuts and the colorimetric coordinates of the target colour are located in 3-dimensional CIELAB colour space. The target colour is then checked against the colour gamut of each sector to find if the colour is inside the gamut or not.

If the target colour is inside a single sector-gamut, then this becomes the best sector for reproducing the target colours. If the target spot colour is inside multiple sector-gamuts, for example CMYK and OMYK sector-gamuts, then the inverse model is applied to each of those sectors. The error metric CIEDE2000 between the model estimated colour and the target colour is calculated. The sector which gives the least CIEDE2000 between the target colour and the model predicted colour is selected as the best sector.

If the target colour is not inside any of the sector-gamuts, then we calculate the distance between the target colour and the closest point on the surface (boundary) of each sector-gamut. The best sector is the one which has the closest boundary point to the target colour, that is, the least distance between the target colour and the boundary point.

Once the best sector is obtained, the colour separation for target colour can be calculated by applying the inverse characterisation model to the best sector. Overall accuracy of the inversion model for the 7-colour offset printing process was calculated by combining all colours in all ink-sectors. Each ink-sector had 1485 colour samples resulting into a total of 5940 target colours for the overall 7-colour process.
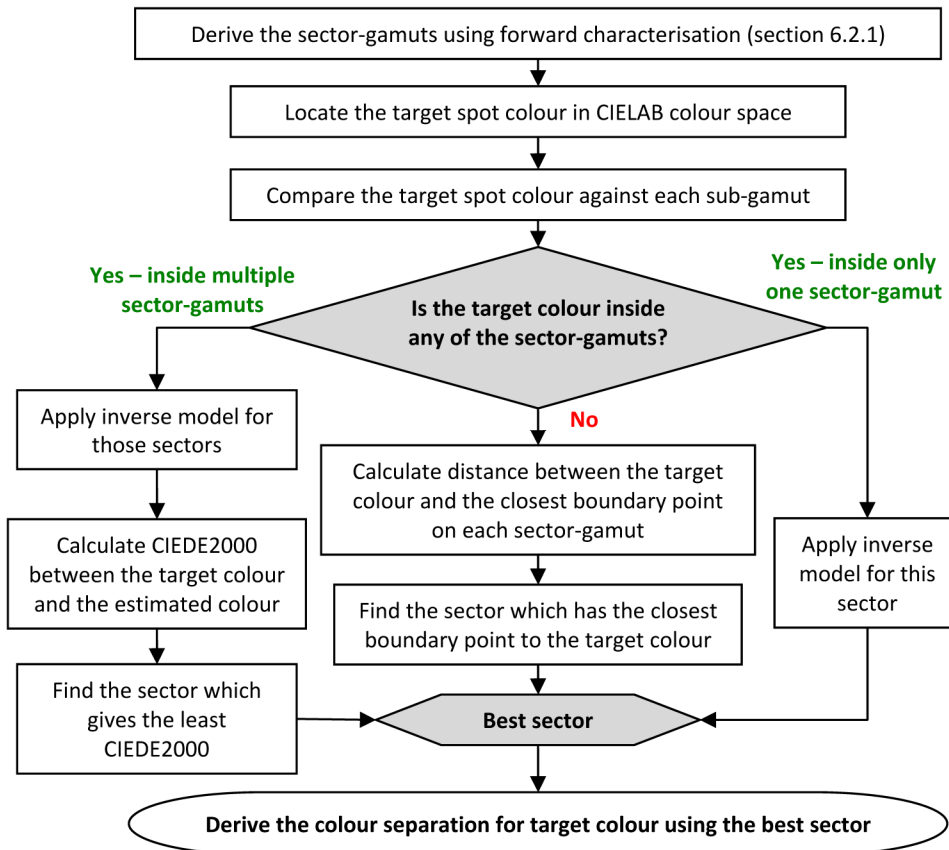
Fig. 7. Deriving the best sector for reproducing the target spot colour.

6. Reproduction of spot colours using the *n*-colour separation

The *n*-colour separation was evaluated by converting a set of 35 real-life spot colours to the 7-colour separation and reproducing these spot colours using the lithographic offset printing process. Following criteria were used to select the spot colours: brand colours of key customers and the distribution of colours across the CIELAB colour space. The colour separation for each of the target spot colours was calculated using the 9-level LUT based inverse methods based on the SCOP model. The colours printed with 7 inks were measured and then compared against the colour measurements of the original spot colours.

The forward characterisation model was applied to each ink sector to build a 9-level lookup table with 6561 coordinates in device space and corresponding CIELAB colour space. The forward characterisation model was used to derive the gamut of each ink-sector. This results into four sector-gamuts.

A test form consisting of 35 spot colours was designed as a TIFF file with CIELAB colour mode. This file was read into Matlab using the 'imread' function. Each spot colour patch had multiple pixels with the identical CIELAB values. For each pixel (spot colour), the best sector of 4-inks was derived. In Matlab, the colour separation for each pixel was calculated by applying the inverse characterisation model for the best sector. This results into 7 channels corresponding to each ink of the 7-colour printing process.

Each channel was saved as a separate TIFF file with 8-bits per pixel using the 'imwrite' function in Matlab. The TIFF file was input to the raster image processor (RIP) to produce the 1-bit data for each ink channel. All the colour management settings were turned off to avoid unwanted colour transformations.

Finally the plates were made using a computer-to-plate (CTP) device. The CTP device was calibrated before making the plates. The plates were used for printing the test form on lithographic offset printing press. Process control parameters for the printing conditions during the press-run were recorded. All the printed colour patches reproduced with the 7-colour printing process were measured using X-Rite i1 Pro 2. The CIEDE2000 values between the printed colours and the original spot colours were calculated. Appendix A shows microscopic views of the rendered spot colours.

7. Results

7.1 Forward printer characterisation

Table 1 shows the prediction accuracy of the SCOP model for all ink sectors of the 7-colour lithographic offset printing process for the test set of 5940 patches. The mean CIEDE2000 values between the predicted colours and the measured colours for all sectors are between 2.80 and 3.52.

Table 1. Accuracy of the forward printer characterisation model

CIEDE2000	CMYK	OMYK	CGYK	CMVK
Mean	2.80	3.20	3.09	3.52
95th Percentile	7.67	8.52	6.96	9.04
Max	15.33	14.09	11.87	15.75

Table 2 shows the values of a set of coefficients for 6 inks. These coefficients were calculated for the solid inks. The prediction accuracy for superposition of the solid inks is poor (Table 3). This will be addressed as a future research topic to improve the accuracy of the model.

Table 2. The values of coefficients for the solid chromatic inks

Ink	Jx	jy	jz	kx	ky	kz
Cyan	0.095	0.064	0.012	0.708	0.774	1.032
Magenta	0.033	0.095	0.131	0.873	0.704	0.676
Yellow	0.009	0.009	0.312	1.038	1.032	0.499
Orange	0.035	0.085	0.287	0.862	0.728	0.507
Green	0.084	0.040	0.188	0.733	0.847	0.602
Violet	0.081	0.107	0.020	0.725	0.672	0.960

Table 3. The prediction accuracy for superposition of the solid inks

Superposition	CIEDE2000	Superposition	CIEDE2000
C + M	5.50	V + C	13.29
C + Y	9.47	V + M	7.57
M + Y	9.24	C + M + Y	10.81
M + O	5.43	M + O + Y	14.09
O + Y	4.87	C + G + Y	7.34
C + G	1.79	V + C + M	4.91
G + Y	10.62		

The SCOP model was also implemented for the 7-colour flexographic and thermal sublimation printing processes. The results for each ink sector are given in Fig. 8. The mean CIEDE2000 values are below 5 except for the orange sector of the flexographic printing process and the violet sector of the thermal sublimation printing process.
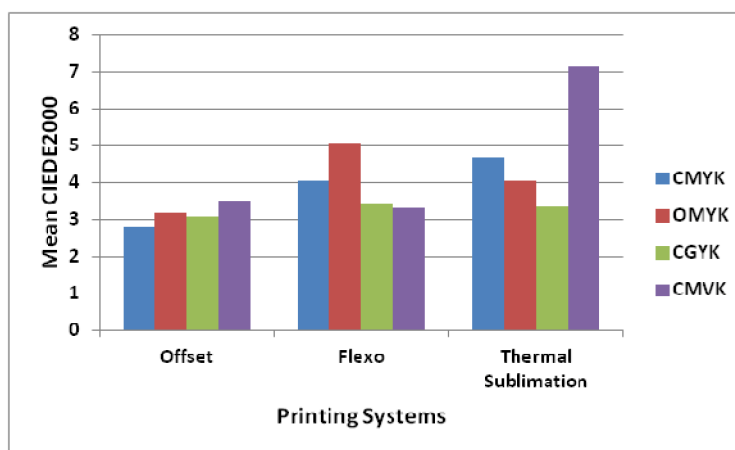
Fig. 8. Performance of the forward printer characterisation model for each sector of the 7-colour printing processes.

7.2 Inverse printer characterisation

Table 4 shows the accuracy of the inverse model for all ink sectors of the offset printing process using the SCOP model for forward characterisation. The mean CIEDE2000 values between the target colours (1485 patches per sector) and the estimated colours are typically below 2. The violet ink-sector showed worse performance than other ink-sectors. As expected the model accuracy improved with the number of LUT-levels. However, there is no significant improvement from 9-level to 17-level LUT. Also the speed performance is dramatically reduced after 9-level LUT.

Figure 9 shows the target colours and the model estimated colours for the green ink-sector in L*-C* plane. Some highly chromatic colours with lightness values between 40 and 50 are not estimated well.

The overall combined accuracy and speed of the 9-level LUT inversion based on the SCOP model is shown in Table 5 for three printing technologies. The mean CIEDE2000 values between the target colours and the estimated colours for all printing technologies are reasonably good given that the inversion is based on a simple forward characterisation model.

Table 4. Accuracy of the inverse printer characterisation model for the offset printing process

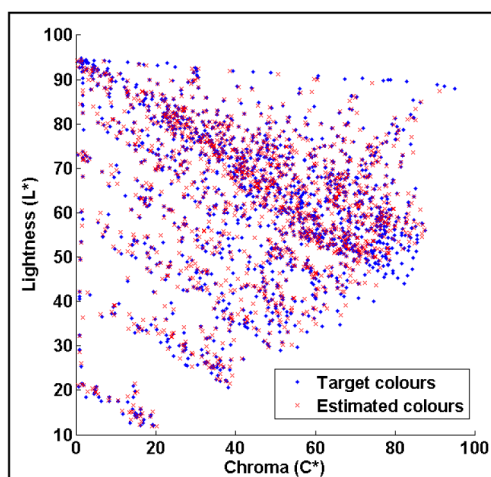| LUT-levels	Sector	CIEDE2000			Speed (mS per colour)
		Mean	95th percentile	Max	
5-level	CMYK	1.81	6.59	15.91	2.58
	OMYK	1.40	5.12	14.16	2.55
	CGYK	1.04	4.09	10.62	2.64
	CMVK	3.08	10.97	17.12	2.64
9-level	CMYK	1.30	4.93	9.62	5.74
	OMYK	1.07	3.86	6.72	5.62
	CGYK	0.73	2.53	8.11	5.53
	CMVK	1.80	6.86	12.36	5.65
17-level	CMYK	1.30	4.71	9.87	26.78
	OMYK	1.00	3.50	6.89	26.75
	CGYK	0.71	2.20	8.00	26.87
	CMVK	1.34	5.35	9.94	26.88

Fig. 9. Distribution of the target colours and the estimated colours in L* - C* plane using 9-level LUT inverse model for CGYK sector.

Table 5. Overall accuracy and speed of the 9-level LUT inverse model for the 7-colour printing processes

Printing Technology	CIEDE2000			Average Speed (ms per colour)
	Mean	95th percentile	Max	
Offset	1.22	4.65	12.36	5.6
Flexography	1.66	5.80	12.13	5.4
Thermal Sublimation	2.21	8.88	28.77	5.9

7.3 Reproduction of spot colours using the n-colour separation

The mean, 95th percentile and maximum values of the CIEDE2000 between the 35 target spot colours and the printed colours are shown in Table 6. The inverse model showed good results with the mean CIEDE2000 of 2.06 with the average speed of 6.9ms per colour. Note that these results are better than the forward model accuracy in Table 1. One reason for the better accuracy in Table 6 may be the limited set of selected spot colours which behave particularly well.

Table 6. Accuracy of the spot colours reproduced with the 7-colour separation on offset printing press

Method	CIEDE2000			Average Speed (ms per colour)
	Mean	95th percentile	Maximum	
SCOP 9-level LUT	2.06	3.68	4.09	6.9

Note that these colour difference values are the results of accumulative error across the reproduction workflow. For example, the model prediction accuracy, error due to the process variables including the printing conditions, measurement uncertainty etc. Although the process control was in place, there are inherent variability contributing to the final colour difference between the printed colours and the original target colours.

7. Conclusion

In spite of the spectral printer models available for printer characterisation, they may not be used in the existing workflows owing to their complexities and computational cost. This is particularly important in an imaging workflow where a large number of pixels are processed. To address this issue, the spot colour overprint (SCOP) model is proposed as a forward printer characterisation model. It was implemented and evaluated for the 7-colour printing processes with different printing technologies, for example, lithographic offset, flexographic and thermal sublimation printing. This model is relatively simple to use and computationally inexpensive. It calculates the resulting colour in CIEXYZ colour space rather than spectral domain. This makes it suitable to be incorporated in ICC workflow and PDF/X documents.

The inverse characterisation model with the look-up table was evaluated to derive the colour separation of the 7-colour printing processes. The SCOP model was used as the forward characterisation model to populate the look-up table. This method can be successfully used to perform the inversion for all three printing technologies. The main advantages are the reduced computational cost due to simplicity of the model and the ink-based characterisation without requiring printing any combinations of multiple inks.

A set of spot colours were reproduced using the 7-colour offset printing process. The colour separation for each of the target spot colours was calculated using the LUT based inverse method based on the SCOP model. The colours printed with 7 inks were measured and then compared against the colour measurements of the original spot colours. The results show that the proposed method can be effectively implemented to replace the spot coloured inks and achieve the target colours with the 7-colour printing process. This could potentially save significant material, time and costs in those market sectors of the packaging industry where the printing jobs mainly consist of the solid spot colours.

Appendix A

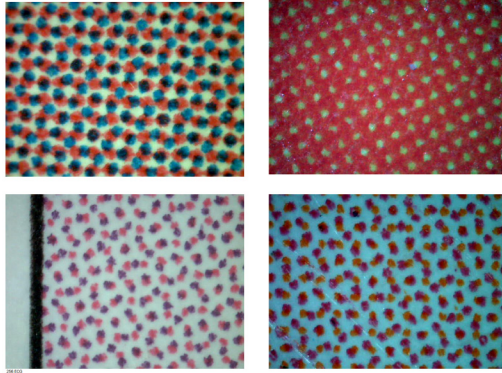Microscopic views of different rendered spot colours are given below in Fig. 10.

Fig. 10. Microscopic views of the rendered spot colours printed with *n*-colour separation.

Acknowledgments