Evaluation of Dye-sublimation Printing Inks Used for Textile Printing

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Abstract

Dye-sublimation printing is a modern digital printing technology that is being used more and more for textile printing. Classifying and identifying ink produced by the different manufacturers can be important to understand and analyse issues like document forgery, poor print quality, and printer service needs in the market. In this paper, we classify and evaluate the performance of dye-sublimation printing inks produced by six different manufacturers. The inks are evaluated in terms of colour and reproduction accuracy on two different textile materials. A weighting coefficient is introduced in the classification threshold to consider different customer requirements like quality, application, and process standardisation during classification. The obtained results indicate that with sufficient spectral measurement data, spectral angle calculated using the spectral angle mapper algorithm and the Mahalanobis distance between the inks, this would be possible.

Keywords

Dye-Sublimation printing Ink, Colour reproduction accuracy, Ink classification

1. Introduction

Digital printing industry is experiencing a more enhanced and innovative growth as compared to the conventional print industry [1]. Dye-Sublimation printing, hereby referred to as dye-sub printing, is one of the major contributors of the digital printing technology. Dye-sub printing is suitable for printing on different media like textile, glass, floor mat, acrylic, and plastics. With increasing use and adoption of dye-sub printing in the textile industry, this printing technique commands a prominent share in the dye-sub printing market in the world [1]. To meet the industry demands many ink manufacturing companies produce dye-sub printing inks that can be used with dye-sub printers manufactured by different companies, and are available at affordable rates for print service providers and consumers. These inks are commonly known as third party inks or compatible inks and hereby referred as compatible inks.

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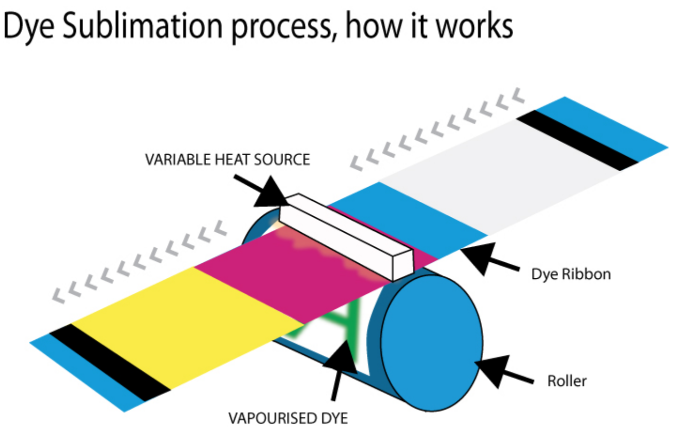


Figure 1: Dye-sublimation printing process. Image taken from[1]

In 2020, EPSON launched a new dye sublimation printer called 'SC- F530' along with its own ink set, hereby referred as original ink, in India which directly compete with the compatible inks already available in the market. To sustain in a highly competitive market, it is crucial for dye-sub printing ink manufacturers, print buyers, and print machine owners to understand and evaluate the performance of these inks thus providing a better service and quality to their customers. Classifying and analysing the inks (original or compatible) used in the dye-sub printing process would help identify document forgery [2], reasons for wear and tear of printing machines, and make true/false claims on reasons for poor print quality and service in the market.

To address this, in this paper we classify the dye-sub printer inks into original and compatible inks using their spectral reflectance information and study ink performance in terms of colour reproduction quality. EPSON SC-F530 dye-sub printer with EPSON provided inks (original inks) were used along with five compatible inks. Given the increasing use of dye-sub printing process in the textile industry, we used two textile materials, 'Polyester' and 'Lycra-cotton' as printing substrates in this study.

The main objective of this paper is to evaluate performance of the original and compatible dye-sub printing inks for print quality in terms of colour reproduction accuracy and classify them using spectral reflectance captured with a spectrophotometer.

2. Background and related work

Dye-sub printing is a modern digital printing technology used in label, banner, decorating novelty items, and textile printing to name a few [3]. The process uses the science of sublimation, in which heat and pressure is applied to a solid, turning it into a gas through an endothermic reaction without passing through the liquid phase[2]. In dye-sublimation printing,

[1] http://www.dyesublimationchina.com/html_news/Principles-and-Applications-of-dye-sublimation-printing-process-87.html

[2] https://hildur.net/an-introduction-to-dye-sublimation-printing/

unique sublimation dyes are transferred to sheets of “transfer” paper via liquid gel ink through a piezoelectric print head. This sheet is then placed on a heat press along with the substrate to be sublimated.

Dye-sub printing inks are made from dye particles. These inks are grounded and then suspended in a liquid that carries them without dissolving in itself. Reverse images are printed using the dye-sub ink on heat resistant sublimation paper (called as transfer paper) for the images to be transferred on the final printing material. There are several variables in dye-sub printing that can affect the final results. The heat, time, pressure, and humidity, all can affect the quality of the obtained final print [3].The dye particle formulation of the ink bonds with polymers thus giving a high percentage of bonding to materials made from polyester. This is also one of the reasons that Dye-sub printing process cannot be used for printing on textile material produced from 100% cotton fabric.

Printing on textiles can be more challenging compared to printing on paper substrates. Depending on the fabric construction (woven or knitted) usually more ink is needed for textiles compared to paper as the ink penetrates into the fabric material of the textile resulting in higher concentration of dyes and pigments compared to inks used in the graphic arts industry [4]. Polyester is a commonly used fabric in textiles and shows advantage when it comes to printing on it using dye-sub printing technology. Chemically, polyester is a polymer consisting of compounds within the ester functional group. Most synthetic and some plant-based polyester fibres are produced using ethylene, a constituent of petroleum but can be derived from other sources as well [5]. Blending polyester with cotton improves the physical properties of the fabric like shrinkage, durability, and wrinkling profile. Fabrics produced using polyester can be highly resistant to environmental conditions like heat, light, pressure, etc making it ideal for long-term use in outdoor applications. Lycra-cotton fabric is made using cotton and fabric material with cotton being the natural material whereas Lycra consists of polyester and spandex material. Lycra-cotton fabric is stretchy and breathable and therefore can be ideal for sports and outdoor activities.

3. Method

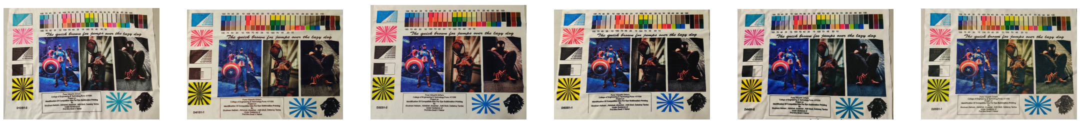
3.1. Print samples and spectral measurement

Inks introduced by EPSON along with their SC-F530 printer were used as original inks (O) along with five different compatible dye-sub printing inks (I) in this study. Textiles, ’Polyester’ ($S1$) and ’Lycra-cotton’ ($S2$), commonly used as T-shirt material, where used as print substrates. A test-chart as shown in Figure 2 and consisting of the Fogra MediaWedge CMYK V3.0, line art and a continuous tone image was generated.

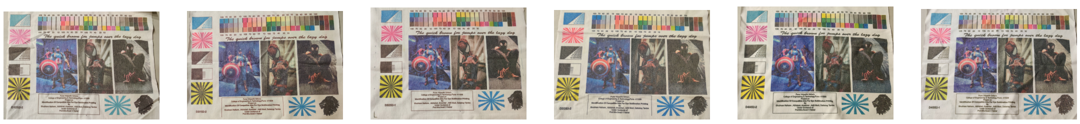
The test-chart was printed on both, S1 and S2, substrates, using the original ink (O) and the compatible inks (I1, I2, I3, I4, and I5). Figure 3 shows the 12 samples obtained using the two substrates and the six dye-sublimation inks. Due to limited access to dye-sublimation printers in the COVID-19 situation, only three copies of samples S1I1 to S1I5 and S2I1 to S2I5 (compatible inks) were printed using the EPSON Ecotank L130 assembled printer whereas three copies of samples S1O and S2O (original inks) were printed using the EPSON SC-F530 printer.

The 72 patches of the Fogra MediaWedge CMYK V3.0 on all the three copies were measured

Figure 2: Test chart printed on both the substrates using the original and compatible inks



(a) $S1O$ (b) $S1I1$ (c) $S1I2$ (d) $S1I3$ (e) $S1I4$ (f) $S1I5$



(g) $S2O$ (h) $S2I1$ (i) $S2I2$ (j) $S2I3$ (k) $S2I4$ (l) $S2I5$

Figure 3: Prints using 2 substrates, an original ink and 5 compatible inks

spectrally using a Xrite I1Pro2 spectrophotometer and averaged. Xrite I1Pro2 measures the spectral reflectance of a material surface in the range of 400nm – 700nm at 10nm interval. CIE XYZ tristimulus values were calculated according to [6] and using the spectral reflectance measurement data of the 72 patches, the CIE 2° colour matching functions and the D50 illuminant [6]. CIE1976 (L*a*b*), and CIE1976 (u´v´) co-ordinates were further calculated according to [6] and using the CIE XYZ tristimulus values.

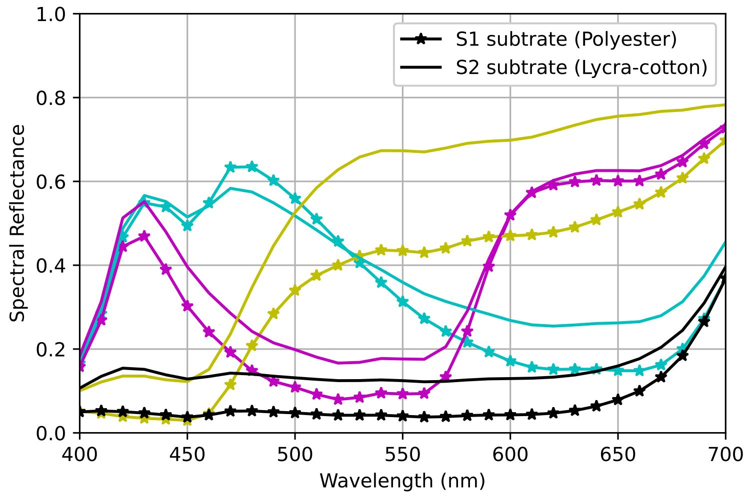


Figure 4: Spectral reflectance of CMYK 100% patches from the Fogra Media Wedge CMYK V3.0 printed using original ink.

3.2. Ink performance in terms of spectral and colour accuracy

To evaluate the performance of the inks, relative spectral error (ΔE_{err_i}) and colorimetric error was calculated between the original and the five compatible inks. Relative spectral error was calculated using Equation (1) where O is the spectral reflectance of the original ink, and I_i is the spectral reflectance of the compatible ink (I1, I2, I3, I4, and I5). Figure 4 shows the spectral reflectance of the cyan (C), magenta (M), yellow (Y), and black (K) 100% patches from the Fogra Media Wedge CMYK V3.0 printed on both the substrates using the original ink.

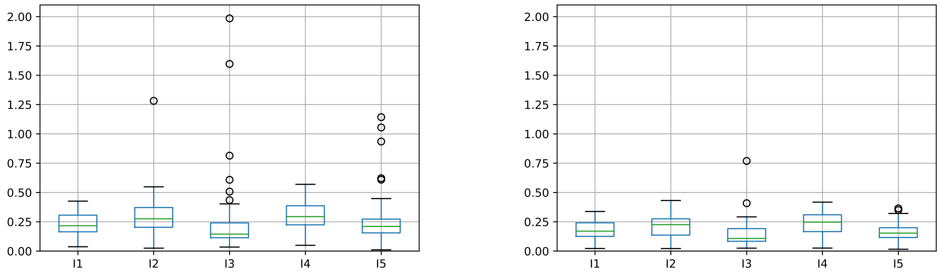
$$\Delta E_{err_i} = \frac{\sum_{400}^{700nm} |O - I_i|}{\sum_{400}^{700nm} O} \tag{1}$$

To colorimetrically evaluate the compatible inks, we calculate the colorimetric difference CIEΔE_{00} [6] between the 72 Fogra Media Wedge CMYK V3.0 patches printed using the original and the five compatible inks on both, Lycra-cotton and Polyester, substrates.

3.3. Ink classification

To classify inks as original and compatible ink, we used the spectral and colorimetric measurements of the 100% solid ink patches (C, M, Y, and K) of the Fogra Media Wedge CMYK V3.0 printed on both the substrates. With the spectral reflectance measurements we used a similarity detecting algorithms, *Spectral Angle Mapper (SAM)* [7]. *SAM* is commonly used in various fields like colour, multi-, and hyper-spectral imaging techniques [8, 9, 10] for classification and identification of different materials using its spectral reflectance measurement.

SAM considers each spectrum as a vector in an n dimensional space, where n is equal to number of spectral bands, and measures spectral similarities between two spectrum by



(a) *Polyester* (b) $Lycra - cotton$

Figure 5: Box-and-whisker plots showing relative error (ΔE_{err}) calculated between original and compatible inks

estimating angle (α) between the two spectra [7]. Value of α will determine the similarity between the original (O) and compatible ink (I) and is calculated using Equation (2). α is calculated in radian with a smaller α value being equal to a higher similarity between the original and compatible ink. α was calculated between the original and the five compatible inks ($i = 1, 2, 3, 4, 5$) for each ink colour (C, M, Y, and K).

$$\alpha_i = \cos^{-1}\left(\frac{(\sum_{400}^{700nm}(O \cdot I_i))}{\sqrt{\sum_{400}^{700nm} O^2} \cdot \sqrt{\sum_{400}^{700nm} I_i^2}}\right) \tag{2}$$

To classify the inks using their colorimetric measurements we calculated the Mahalanobis distance [11] between the original and compatible inks in the CIE1976 (u´v´) chromaticity co-ordinate system using Equation (3). CIE1976 (u´v´) chromaticity co-ordinates are projected transforms of the CIEXYZ tristimulus measurements and therefore they discount the magnitude change that may be seen between the original and compatible ink measurements.

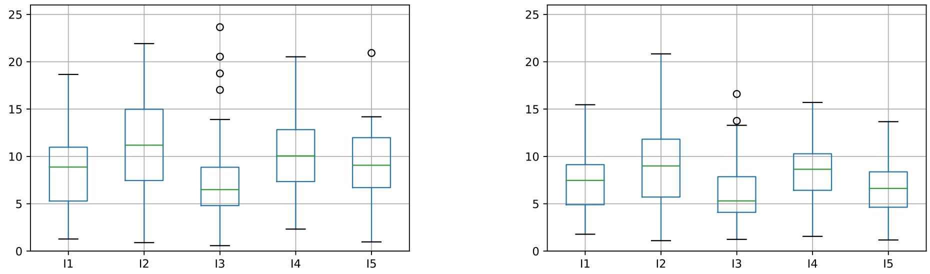
$$D = \sqrt{(h - m)^T \cdot C^{-1} \cdot (h - m)} \tag{3}$$

In Equation (3), D is the Mahalanobis distance, h is the vector of the CIE1976 (u´v´) chromaticity co-ordinate measurements of the original ink, m is the mean values of the independent variables (u´v´ values of the original ink measurements), and C^{-1} is the inverse co-variance matrix of the independent variables.

4. Results

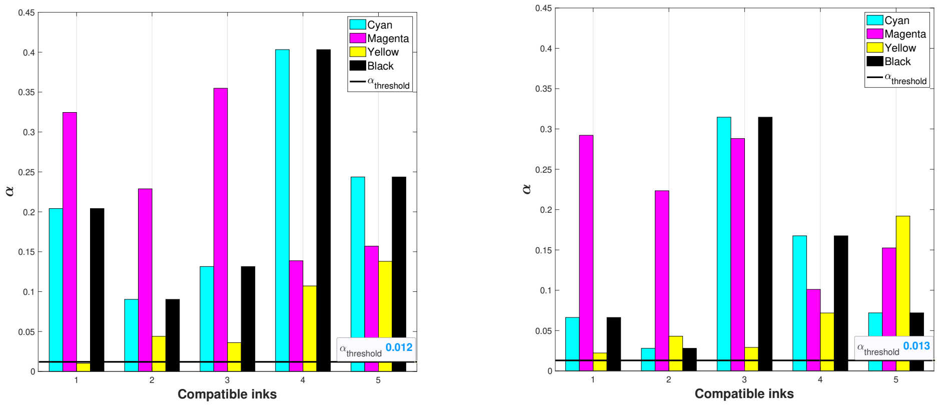
Figure 5 and 6 shows the box-and-whisker plot for the relative error (ΔE_{err}) and the colorimetric difference CIEΔE_{00} [6] calculated between the original and the five compatible inks.

α value was calculated between the original ink and the compatible inks printed on both the substrates using Equation (2). To classify the inks as original or compatible, a classification



(a) *Polyester* (b) *Lycra − cotton*

Figure 6: Box-and-whisker plots showing colorimetric error (ΔE_{00}) calculated between original and compatible inks



(a) *Polyester* (b) *Lycra − cotton*

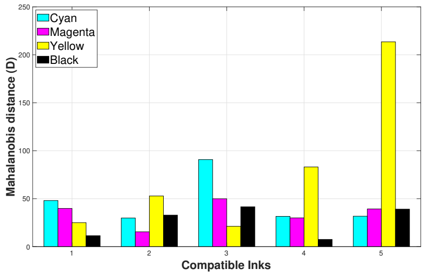
Figure 7: α value calculated between original and compatible inks printed on both the substrates

threshold (α_{thresh}) was defined using Equation (4).

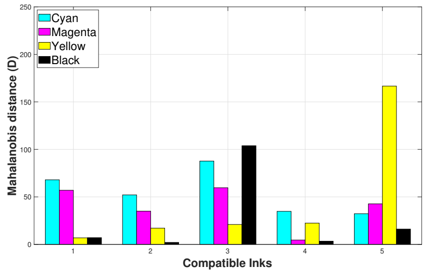
$$\alpha_{thres} = \frac{\rho}{e} \cdot \sqrt{\sum_{i=1}^{e} (\alpha_{ori})^2} \tag{4}$$

In Equation (4), α_{ori} is calculated using Equation (2) between the original ink measurements and their average, e is the total number of times the original ink was measured. ρ is a weighting coefficient in Equation (4) that can be defined based on requirements like printing application, process standardisation, and print accuracy/quality requirement as per customer requirements. In this study we did set $\rho = 1.0$. Figure 7 shows the SAM measurements calculated using Equation (2) and (4).

Mahalanobis distance (D) was calculated in the (u'v') chromaticity coordinate space between the original and compatible inks using Equation (3). In Equation (3), vector h represents the



(a) *Polyester*



(b) *Lycra − cotton*

Figure 8: Mahalanobis distance calculated using Equation (3)

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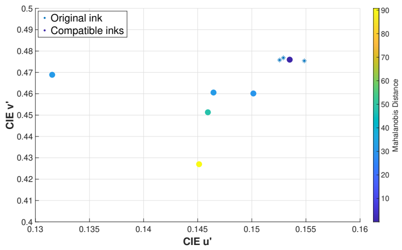
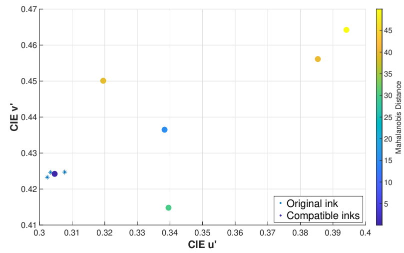
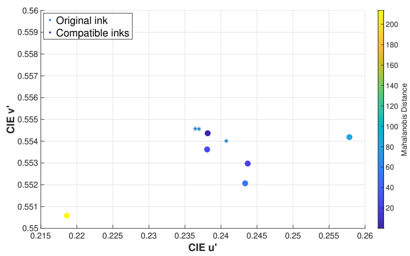


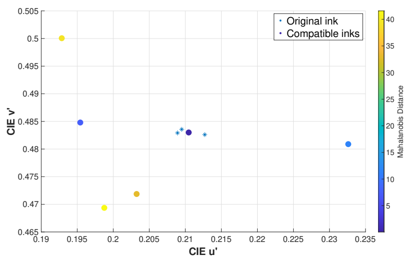
(a) *Cyan*



(b) *Magenta*



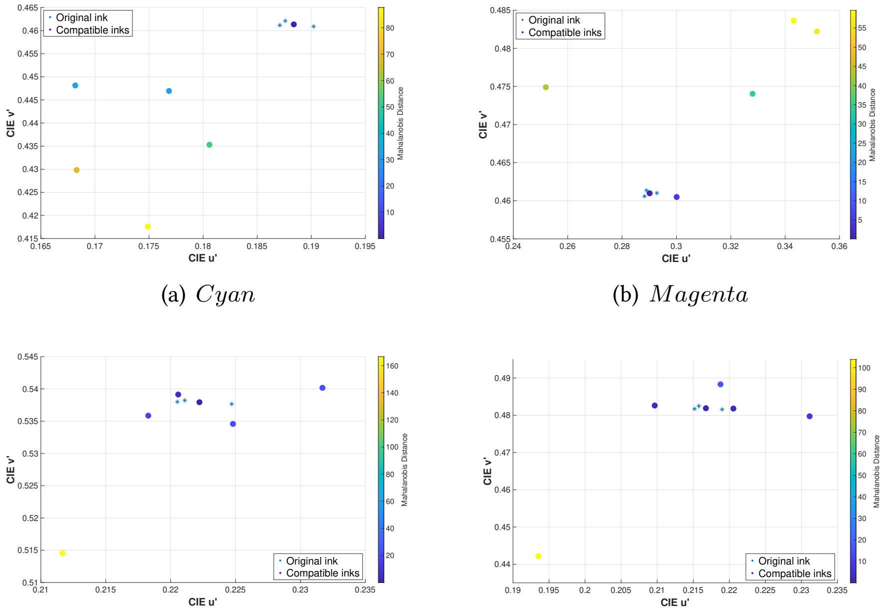
(c) *Yellow*



(d) *Black*

Figure 9: Mahalanobis distance (D) and the original and compatible inks printed on the Polyester substrate in the CIE1976 (u'v') chromaticity coordinate system.

compatible ink (I_1, I_2, I_3, I_4, and I_5) measurements, m is a vector of the mean values of the O_e measurements (where O is the original ink and e is equal to 3 measurements in total), and C^{-1} is the inverse co-variance matrix of the O_e measurements. Figure 8 shows the Mahalanobis distance calculated for the compatible inks using Equation (3). Figure 10 shows the compatible inks and their Mahalanobis distances in the CIE1976 (u´v´) chromaticity co-ordinate system.



(a) *Cyan* (b) *Magenta*

(c) *Yellow* (d) *Black*

Figure 10: Mahalanobis distance (D) and the original and compatible inks printed on the Lycra-cotton substrate in the CIE1976 (u'v') chromaticity coordinate system.

5. Discussion

We evaluated the performance and classified the original and compatible dye-sub printing inks using their spectral reflectance measured with a spectrophotometer on two textile substrates. Both the substrates have been used with dye-sub printing for manufacturing printed T-shirts in the clothing industry.

To quantitatively evaluate the reproduction quality, relative spectral error and colorimetric error was calculated between the Fogra Media Wedge CMYK V3.0 printed using the original and compatible dye-sub printing inks. From the box-and-whisker plots it is observed that compatible ink I3 showed the least error however with a few outliers.

We used the SAM technique for ink classification using the spectral reflectance measurements. Lower the value of the spectral angle (α), more similar are the inks spectrally. Figure 7 shows the α values obtained between the original and compatible inks for the solid C, M, Y, and K ink patches in the Fogra Media Wedge CMYK V3.0 printed on the textile substrates. Magenta compatible ink consistently showed a higher α value compared to C, Y, and K compatible inks. Classification threshold as defined in Equation (4) was used. The term ρ in Equation (4) can be defined depending upon different quality requirements and printing applications from customer, ink manufacturers, and printers. Due to COVID-19 situation, availability and access to printing and measurement facilities was limited and therefore only 3 print samples ($e = 3$) were generated using each, the original and compatible ink, and measured spectrally using the X-rite I1 Pro spectrophotometer. With the obtained results we see that the sample size ($e = 3$)

is very small and more measurements are needed.

Mahalanobis distance was calculated between the original and compatible inks using Equation (3). Mahalanobis distance calculates the distance relative to the centroid of the multivariate data (original ink measurements ($e = 3$) in this paper). More spectral reflectance measurements of the original ink are required as the distance is calculated relative to the centroid. Figure 8 shows the Mahalanobis distance calculated using Equation (3).

6. Conclusion

Performance of dye-sub printing inks was evaluated for colour reproduction accuracy on 2 textile materials, Polyester and Lycra-Cotton. The inks were classified between original and compatible inks using their spectral reflectance measurements to calculate a spectral angle using the SAM technique and the Mahalanobis distance in the colorimetric space CIE1976 (u´v´). A weighting coefficient was introduced in the classification threshold equation that will help classify the original and compatible dye-sub printing inks based on customer requirements like printing application, process standardisation, and print accuracy/quality.

Given the COVID-19 restrictions, limited spectral reflectance data was collected and more is clearly needed to classify the inks as original and compatible dye-sub printing inks with a good accuracy. With more spectral measurements, this simple spectral angle mapper technique and the Mahalanobis distance can be used to classify dye-sub printing inks into original and compatible inks and help different needs of printers, ink manufacturers, and customers.

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