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Colour and spectral simulation of textile samples onto paper: a feasibility study

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This study has investigated how the growing technology of multichannel printing and the area of spectral printing in the graphic arts could help the textile industry to communicate accurate colour. In order to reduce the cost, printed samples that serve for colour judgment and decision making in the design process are required. With the increased colour gamut of multichannel printing systems we are expecting to include most of the colours of textile samples. The results show that with careful control of ink limits and with bypassing the colour management limitations imposed on printing system; we are able to include more than 90% of colour textile samples within the multichannel printer colour gamut. Also we evaluated how much textile colours spectra we can print with multichannel printers. This gives a basis for further work in the area of spectral printing, and particularly for the application area discussed in this study. By comparison of spectral gamuts, we also conclude here that it is possible to print around 75% of all reflectance from textile colours.

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Introduction

A fundamental requirement for any colour management paradigm is unambiguous colour communication. Due to the physical nature of materials and colorants used in different industries, different colour management standards and workflows have been adopted. In the graphic arts (printing) industry, the dominant colour management workflow is that standardised by the International Color Consortium (ICC) and is based on metameric reproduction [1]. In printing, where four channel metameric reproductions has been the cornerstone of hard copy colour output for more than a century, recently, additional channels (beyond the common CMYK) have been introduced to extend the colour gamut where conventional printing systems have shortcomings.

In previous preliminary work [2, 3], we evaluated whether it was possible to include all textile colours within the printable colour gamut of four and more colour printers. A particular challenge in that study was to evaluate whether it would be possible to reproduce textile samples within a given range of colour accuracy. These samples were 5 cm x 5 cm pieces of fabric that are normally produced within 0.8 ΔE_{CMC} tolerance from a reference set. The colour difference was evaluated for the UL3000 store illuminant and 10 degrees colorimetric observer. Designers use these physical samples when they are deciding which shade an item of garment product will be, or which shade needs to be placed next to each other in a printed or yarn dyed pattern on a garment product. The existing set of roughly 4000 colours is supporting the design process within the colour set that designers are able to pick from. Once their colours for a season and brand are chosen, fabric samples are ordered to work with. The possibility of printing these colour samples versus purchasing them from a dyeing company would significantly reduce cost.

With four channel printing technology, such reproduction is not feasible [2]. With the addition of red, green and blue printing channels, the expansion of the gamut was found to be significant and many more textile colours were included in the printable gamut [3]. However this is still not sufficient to be acceptable for such applications. Many dark colours are still out of the gamut and the particular ink configuration was not optimal for reproduction of the textile colours.

Now we seek to find custom printing method that resembles a workflow similar to one used in spectral printing. As the ultimate goal is to have both colour and spectral match, we aim to establish a starting point for spectral reproduction workflow for textile colour simulation onto paper. Multichannel printing systems has provided with a good tool for spectral reproduction [4-7]. Major goals of the spectral printing are spectral and colour accuracy, and reduced metamerism [8]. This corresponds well with our intentions and therefore we will use such workflow.

Application areas where spectral printing can be applied includes highly accurate industrial colour communication in terms of colour swatches, catalogues and samples (e.g. textile and paint industry), spectral proofing, fine art reproduction, and security printing [9]. All these applications would typically require optimal colorant sets to comprise the gamut of the original. The first step toward achieving accurate reproduction is to have all colours and spectra within the printable gamut. Therefore, the aim of this study is to evaluate how many of the textile sample colours and spectra we can include into the available gamut of multichannel printing technologies using different substrates.

Method

The comparison of the printer gamut was performed with 4872 textile colour samples and spectra with the multichannel printer colour and spectral gamut. We used the Color Think software to visualise gamuts in CIELAB space, in both two and three dimensions. To represent the spectral gamut we first use Principal Component Analysis (PCA) to reduce the dimensionality of input spectra that define the printer spectral space [3, 10]. Here we used rotated Principal Components that could be considered as colorant spectra of a particular device [11]. Our multichannel printer utilises seven independent channels and subsequently we obtain first seven basis vectors from PCA and then compute the convex hull. From the borders of each intersection within a hyper-plane, the target reflectance is found as a distance or vector position relative to the borders. To evaluate if the target vector distance (position) is within the convex hull, we use the *inhull* Matlab function [12]. As this function does not include spectra that are located on the border of the convex hull, we further set the limit and “desaturate” target spectra to obtain the complete in-gamut information. Although we are not considering any gamut mapping within this work, we could obtain the distance or how far from the spectral gamut borders certain points are located.

Experimental setup

A custom printing process has been employed to bypass any colour management including Grey Component Replacement (GCR), and to calibrate ink limitations per channel to provide a maximum gamut and to obtain greater variability in the dark region where many textile colours are located [2]. To establish full control of multichannel printer one must be able to control each channel independently from the others.

We used the ONYX RIP to drive our twelve channel printer (HP Z3200 ink-jet). Although the printer is equipped with light/diluted inks and special colours, for our purposes we consider only seven independent channels (CMYKRGB). The printer is driven through the information from a 7-channel tiff file where digital values for each channel are encoded. The substrates used for printing were HP Artists Matte Canvas and HP Premium Matte Photo Paper. The former has surface structure that best resembles texture of the textile-like material, where the latter has the largest gamut, especially in dark areas (using Photo Black colour).

In order to have a meaningful comparison between textile and paper printed samples we compensate for the differences in measurement methodology. In graphic arts the standard measurement geometry is 0:45, whereas in the textile industry, the standard instrumentation has d:8 geometry. The latter integrates incoming light and effectively neglects the texture of the textile material. The instruments used in our study were GretagMacbeth i1 and Datacolor 6500 which has much more sensitivity in dark region.

Sample preparation for measurement of textile assumes double folded material. Due to the nature of sample preparation for a measurement, and the texture of the surfaces, when two textile samples are compared, the most commonly used colour difference formula is ΔE_{CMC} with the L channel normalised by a factor 2. The same approach could be applied to the comparison of the coloured textile and paper printed sample.

Results and Discussion

The colour comparison starts with gamut plots obtained after establishing custom printing workflow, where each channel of the printer is controlled and where ink limitation setup allowed for each channel to go to its maximum for a given substrate. Further on, we have included primaries ramps (CMYKRGB) measured with Datacolor 6500 d:8 instrument. This allowed us to visualise the difference produced by these measurement geometries.

It can be seen from Figure 1 that most of the textile colours that are outside of the printable gamut are located in the section of low lightness. All the sample colours are within a* and b* dimension of the gamut volume but they tend to be out of the printable gamut in the lower part of the lightness (L*) axis.

The paper surface that is used for this evaluation has high scattering properties and low ink penetration. Also, the structure of the canvas type material leaves some unprinted part of the elevated surface and this can cause the full gamut volume higher lightness values. Therefore some of the dark samples cannot be reproduced with this material. An alternative would be to use a different substrate for this group of the samples or to simulate them with coloured, dyed paper. In Figure 2, we plot all colours in hue-saturation direction using both canvas and photo paper. The photo paper provides wider gamut range, even in dark areas. Note however that these measurements neglect gloss effect which would induce significant appearance differences that makes it unsuitable for simulation of textile material.

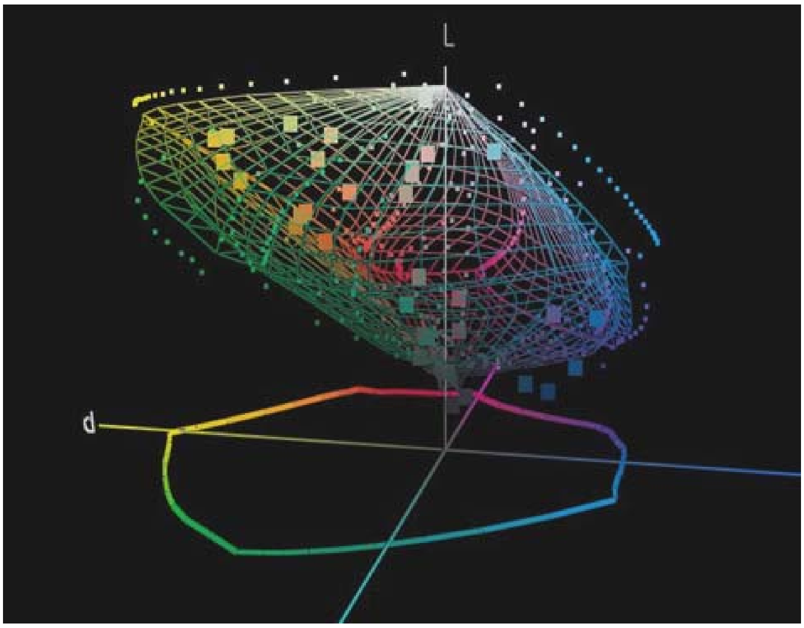

Figure 1: The plot of the basic gamut with ink limitation control and measurement with 0:45 geometry (wireframe), gamut regions measured with d:8 geometry (smaller squares) and sampled textile colour (larger squares).

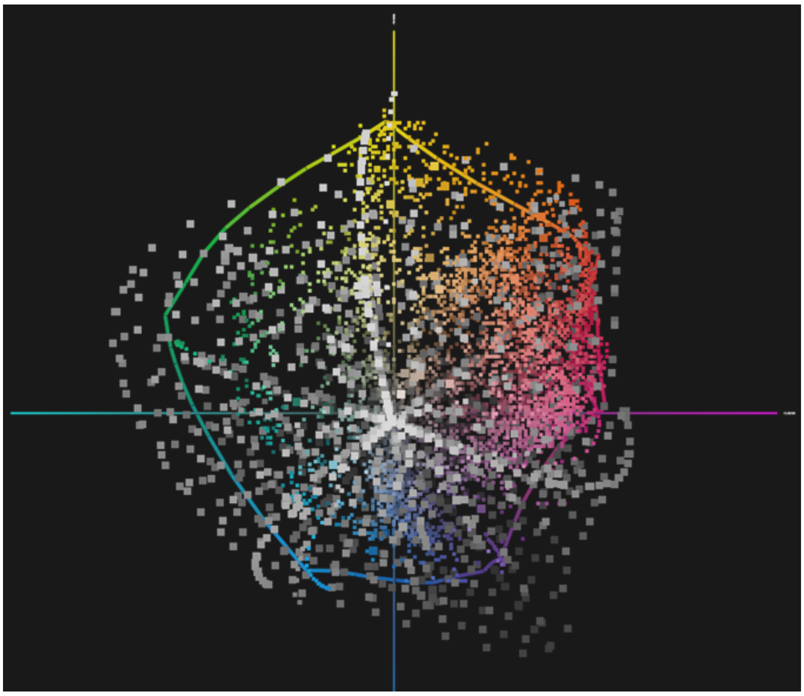

Figure 2: 2D plot of 4872 textile colours (colour points), HP Canvas matte substrate (line frame), white points (photo-paper).

From Figure 2 we can conclude that there are some issues in orange-red region where even with photo paper we are not able to meet this section. Addition of orange colour (to all others) that is present in some multichannel printing systems would improve simulation. Also, exclusion of the GCR increases variability in dark region (e.g. by mixing three or more colours), and even if this is not feasible in terms of ink consumption, spectral or multichannel printing should not be concerned by that. In Table 1, we summarise this comparison in terms of ΔE_{CMC} colour difference.

illuminant	ΔE_{CMC}		
	min	max	mean
D50	0.13	5.5	1.1
D65	0.13	4.9	1.28
A	0.13	4.4	1.2
F2	0.1	4.2	1.05
UL3000	0.1	3.9	1.02

Table 1: ΔE_{CMC} Colour difference between printed and textile samples after application of ink limitation on each controlled channel and measurements with d:8 geometry.

With the exception of the dark colours and the orange sector, the differences between colours seems to not be visible. This would effectively mean that this process is feasible after some adjustments. However we can have no such claims on overall appearance of the samples where texture might play large role.

Now we perform spectral analysis where printer space is represented as a seven dimensional convex hull constrained with basis vectors. These basis vectors are derived through PCA and they reduce dimensionality from e.g. 36 (380-730 in 10nm step) to 7. Therefore, we selected first seven PC that corresponds to the number of independent colorants within our multichannel printing system. To make the analysis more intuitive, we have performed varimax rotation of the basis vectors which yields spectral curves that closely resembles reflectances of the primary colorants (Figure 3).

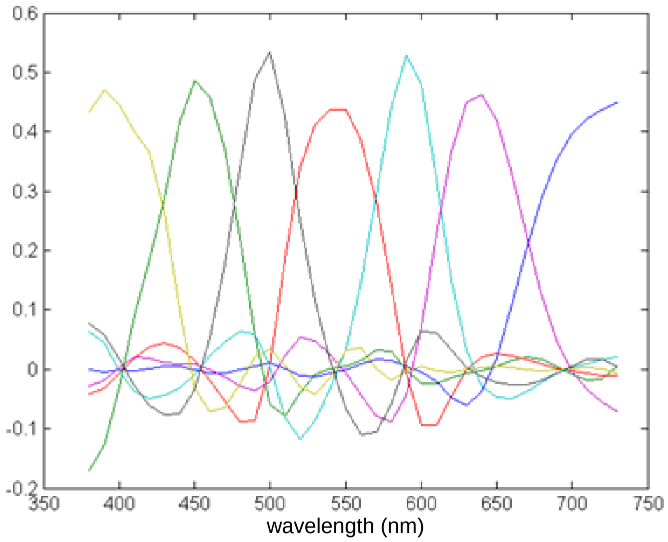

Figure 3: First seven basis vectors spanning the printer space with varimax rotation applied to reduce negative components of the PC.

The cross sections through the seven dimensional convex hull are represented as three dimensional objects projected on two dimensional planes. This is a rather convenient way to visualise spectral gamuts and corresponds to some of the previous attempts [5, 10]. Slices that are represented here combine two basis vectors (1st and 2nd , 3rd and 4th , 5th and 6th) where the *convhulln* function has been used to obtain indices of the hull (Figure 4). Approximated spectral gamuts can then be compared with reflectance (textile samples) transformed to the same PCA space.

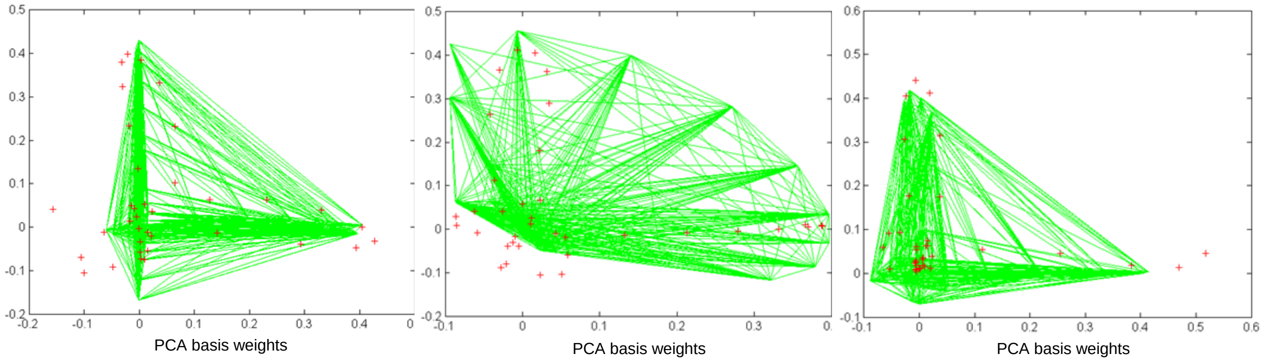

Figure 4: Different views of the convex hull of two first basis vectors (green object) and test points (red pluses). The figures show two dimensional projections (cross sections) of 3D objects where the two basis vectors combine.

Furthermore, we used the *inhull* function to evaluate the number and percentage of spectra that could be included in the spectral printer gamut. Out of the 4872 evaluated textile reflectances, it is possible to include 3939 within the spectral printer gamut. This corresponds to around 75% of evaluated reflectances with maximum RMS = 0.22 for out-of-gamut reflectances. As it was case previously (colour gamut comparison), the most error occurs within low reflective area and orange sector. This can be seen from the right-hand graph in Figure 4 which is the combination of 5th and 6th PC that are corresponds to orange – red sector.

Additional analysis can be found in Table 2 where we evaluated how the spectral gamut coverage is reduced with dimensions added. Generally, adding more basis vectors will improve recovery of the spectra within the data set. However, when comparing spectral gamuts, more dimensions do not necessarily imply higher spectral coverage. Although spectral variation is better represented with greater number of PCs, the reflectance differs depending on the space it occupies [5]. For this reason there is a decrease in overall spectral coverage of the multidimensional gamut where the variability and spectral error within data set improves.

PCA	% variability included	% in gamut	Mean RMS (in- gamut)	Max RMS (out of gamut)
3D	98.3%	88%	0.041	0.22
4D	99.9%	76%	0.033	0.21
5D	100%	73%	0.028	0.15
6D	100%	65%	0.025	0.15
7D	100%	52%	0.022	0.14

Table 2: Spectral and dimensionality analysis printable reflectance of textile colours.

One way to explain this is when we have all colours within 2D gamut (e.g. hue, saturation – Figure 3) and not in 3D (when lightness added – Figure 2).

The difference between the percentage of spectral and colour coverage lies in fact that multiple reflectances can map to the same colour (metamerism). Other reason why more spectra are outside the gamut that it is colour (75% vs 90%) is in representation of the spectral gamut and in the nature of colorants. Namely we are dealing here with essentially different chemicals used for coloration (ink vs dye) that have different spectral properties but can map to same colour. Also when we increase dimensions to represent the gamut, there is always a possibility of match in lower dimensions that would not match in higher dimensions. However, as metamerism is one of the biggest problems in textile industry colour matching, spectral analysis is gaining importance and should be included in reproduction chain.

Another option would be to use a reproduction chain within a given set of illuminants used in graphic arts and textile industry and to perform gamut mapping in these restricted multi-illuminant spaces [8]. Also the evaluation of the difference could be performed using a multi-illuminant metric [5] as working in spectral space does not necessarily correlate very well with a perceptual space.

Spectral gamut analysis could be further used as a base for spectral gamut mapping [10]. In this study we have been more concerned with in-gamut spectra but there is a possibility to determine distance of the points (reflectances) from the gamut boundary, and to use this to decide or optimise spectral gamut mapping algorithms.

Conclusions

In this work we have presented two alternatives for the reproduction of textile colours onto paper substrates. With multichannel ink-jet systems, it is much more likely that we can accurately reproduce textile colours and spectra. To maximise the capabilities of these devices, the full spectral printing workflow should be established. There the maximum potential of the available inks will be used, as well as the control of the individual channels. Also, a colorant selection process should be performed in order to address the shortcomings that current multichannel systems have for this application.

The reduced dimensionality of the spectral space of a printer leads to the possibility of representing a multidimensional gamut as a convex hull of reasonable dimensionality. The approximated spectral gamut can then be compared with reflectances transformed to the same PCA space where different cross sections can lead to useful visualisations of the spectral gamut. Spectral analysis shows that 75% of textile colours spectra can be included in printable spectral gamut. As many of these colours (25% at least) have its metamers that maps to the same point in colour space, alternative approach to the reproduction should be used.

In a colour workflow, it is feasible to use multichannel printers for simulation of textile colours while a pure spectral workflow is still not satisfying.

Although the texture has its influence to colour perception of the sample is not evaluated here, it should be addressed in future work.

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