Colour Management of Prints with Variant Gloss

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Abstract

Advanced printing techniques are currently used to incorporate special effects in printouts. There is an increasing interest in the reproduction of material appearances and art work, with the focus on reproducing aspects such as colour, surface texture and gloss variations. However, for material surfaces of which the level of glossiness varies, the colour is often affected due to the applied gloss effect. The effect of the (local) gloss level on the colour is not incorporated in the colour management, which results in a mismatch with respect to the intended colour. We propose a workflow to control the reproduction of colour for the case of using multiple gloss modes in a printing system. Although currently one single ICC profile is used to manage the colour of the printout, our workflow proposes using one ICC profile per gloss level that adapts the colour transformations locally based on the applied gloss level. Our results show an improved reproduction of the colour and smoother colour transitions between gloss levels of prints with variant gloss.

Introduction

Advanced printing techniques [1] [2] [3] are increasingly used to control additional aspects of a printout. One of those aspects is the ability to locally control the reflection properties of the printout by obtaining a variation of surface gloss appearance. Besides the application of creating watermarks and adding special effects to the printout [4] [5], control of the local gloss level is used to reproduce material appearances and fine art. Especially for the reproduction of fine art, a precise reproduction of the (local) gloss level is important to achieve the overall desired appearance [6], as gloss levels are characteristic for a certain type of art work, art movement and artist [7].

Several printing techniques are currently used in digital prints to control the gloss level of the printout. Gloss levels are controlled either by using varnish layers or additional inks with different reflection properties [2], by controlling the surface roughness of the printout using a build-up of multiple ink layers [3], or by controlling the placement of ink on the paper using more advance print modes [8] [9]. By mixing different print parameters, the gloss level can be controlled globally, resulting in the same gloss level for the whole printout, or locally, where the gloss level can be controlled on each location of the printout. In the printing industry, colour and gloss levels of printed samples are usually measured under well-defined viewing geometries and illumination conditions. Generally speaking, the colour of a sample is determined by measuring the spectral reflectance curve, measured orthogonal to the sample while illuminated under a 45° angle. On the other hand, the gloss level is usually determined by illuminating a sample under an angle of either 20°, 60° or 85°, and measuring the amount of reflected light on the respectively opposite angle. This value is expressed in gloss units (GU), defined in such a way that a glossy material with a refractive index of 1.567 has the value of 100 GU for any illumination angle [10]. In our research, we focus on these well-defined measurements standards to determine the colour and gloss level of printouts and to propose a workflow in which the colour and gloss level of a printout can be both managed according to these measurement geometries.

For most of the materials, the gloss level is directly related to the surface roughness. For a glossy sample, characterised by a smooth surface, the specular reflected light is reflected ideally in the main direction of the reflection in an angle which is equal to the incidence angle of illumination. On the other hand, for a more matte sample, characterised by a rough surface, the specular reflected light is scattered in all directions due to the micro texture of the surface. This also explains the colour shift for the measurement under a 45/0 geometry, where for matte samples, the colour is diluted by the diffused light reflected on the print surface and therefore appears less saturated [11]. Previously, this effect of the gloss level on the colour appearance has been described [12] and shown for printouts and other material surfaces [13].

To gain a better understanding of printed patches with different gloss levels, we used a prototype printer and created a set of patches using different print modes. Here, a "print mode" is defined as a set of print parameters that are chosen to achieve a certain gloss level by influencing the print surface characteristics. Coloured patches were printed with an equal amount of ink deposition while six different print modes were used to obtain a variation of gloss levels in a range from matte to medium gloss. Through a psychophysical experiment [3] the patches were assessed based on their gloss appearance. The majority of the observers reported a colour change between gloss levels, which indicated that colour and gloss cannot be treated independently leading to our goal of managing both colour and gloss simultaneously.

In the following chapter we describe our proposed workflow to manage the colour for a printout with varying gloss levels. Next, we describe an experiment that was conducted to evaluate the proposed workflow in comparison with a naïve approach. Finally, we discuss the results and the improvements of using our proposed solution.

Multi Profile Workflow

Colour management is used in a calibrated printing system, to determine the mixture of ink levels that results in the intended colour for a specific measurement geometry, e.g. 45/0. For special print applications, either additional treatment, extra inks (e.g. varnish), or special print modes are used to adjust the gloss appearance of the printout, which may be applied on selected regions. In Figure 1, such an effect is shown, where a specular gloss mask

(a) RGB image

(b) gloss mask

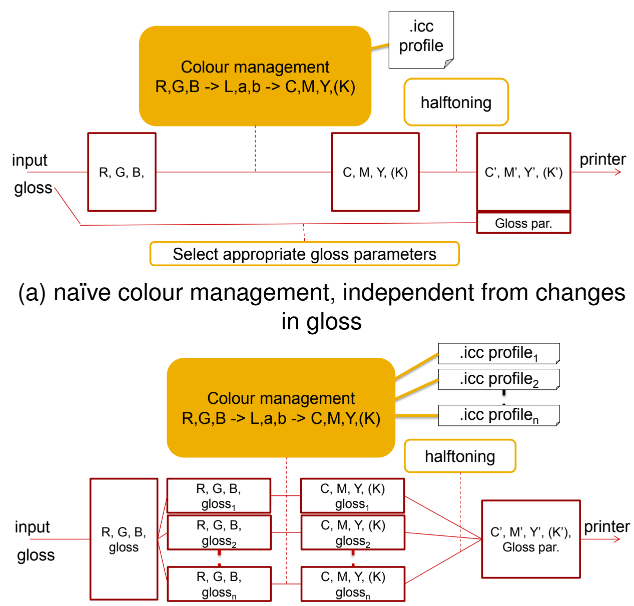
(c) single profile

(d) multi profiles

Figure 1. *Image (a) is printed with two intended local gloss levels described by (b) where white corresponds to 'matte' and black to 'gloss'. In (c) the printout shows colour inconsistencies between varying gloss modes, while the printout in (d) shows colour consistent transitions, using our proposed multi profile workflow. For display purposes, the photographs of printouts (c) and (d) are rendered with exaggerated contrast.*

(Figure 1 (b)) specifies the intended gloss level on each location of the printout. In this example, black corresponds to an intended glossy appearance and white to a matte appearance. The gloss variation is acquired by locally adjusting the corresponding print parameters that generate such variations. Due to the fact that the colours are affected by the applied gloss levels, resulting colours are different from the intended. These differences are clearly visible around transitions between parts of the printout with different gloss levels, as can be seen in Figure 1 (c). This artefact is due to the use of a workflow where gloss levels are varied after colour management is performed. We attempt to obtain colour accurate reproductions and transitions independent of the applied gloss level.

The diagram of Figure 2 (a), illustrates the naïve approach that is mainly used to obtain gloss effects in a printing system, where the colour management is performed independent on the applied gloss level. The first step in the process is the colour management using an ICC profile [14] for the colour transformation. In the next steps, the image is halftoned and gloss parameters are defined to create the intended gloss level locally. We used an alternative approach of colour management, where the colour transformation is dependent on the gloss level that is applied. For a printing system with n available gloss modes, we propose to obtain an ICC profile per mode, resulting in a transformation from an input colour to ink coverages for each gloss level. This multi colour workflow, from now on referred to as 'multi profile', is shown in Figure 2 (b) where different ICC profiles are applied locally, one for each of the n gloss modes. Colour management is not performed globally for the whole image but locally and dependent on the gloss level that is applied. An issue of the proposed solution could be the inaccuracies of the colour transformations introduced by trying to spatially combine multiple ICC profiles to match a desired the colour appearance. To evaluate the improvements of colour reproduction, we conducted an experiment using this workflow, which is described in the following section.



(a) naïve colour management, independent from changes in gloss

(b) proposed multi profile colour management

Figure 2. *Gloss-independent colour workflow (a) where print parameters to control gloss and colour are treated separately, resulting in colour shifts due to the applied gloss. We propose workflow (b) to determine print parameters based on both the intended colour and the gloss level, enabling colour consistent transitions between local differences in gloss levels.*

Implementation and Performance of Multi Profile Workflow

An experiment was conducted to evaluate the improvement of using the proposed workflow as shown in Figure 2 (b), where

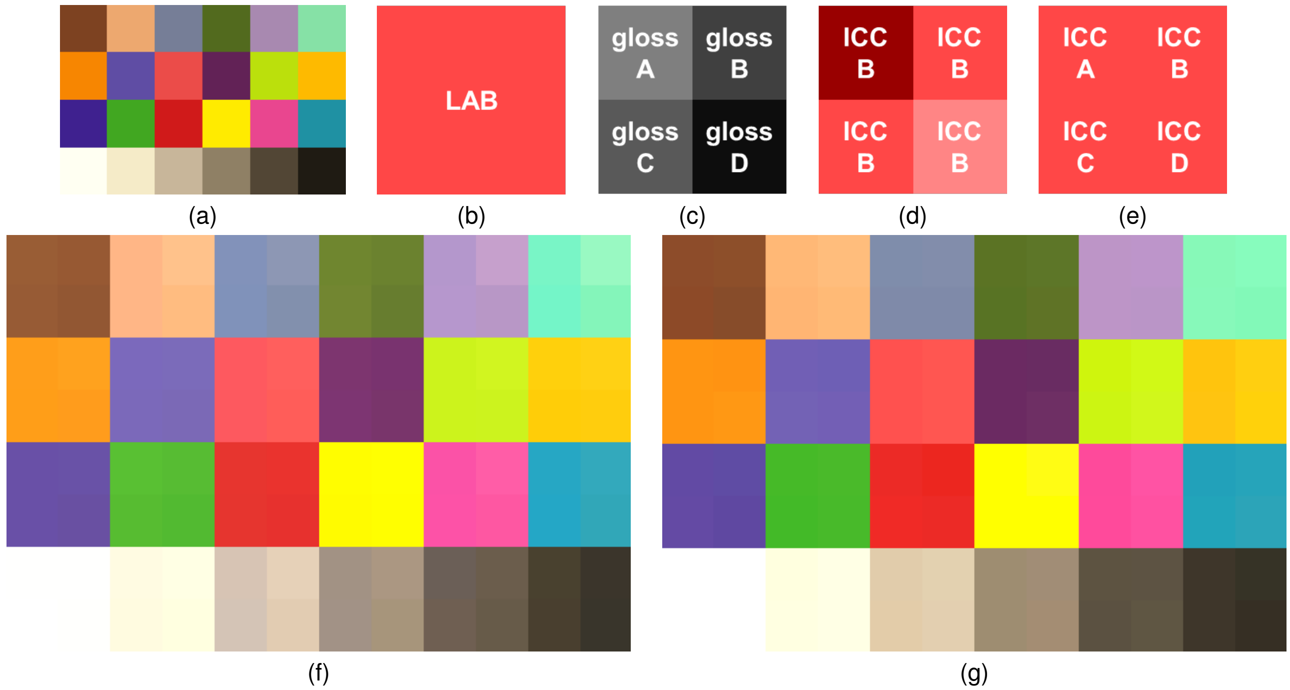


Figure 3. *Roundtrip test where each patch (b) of image (a), containing information of intended colour, is subdivided in smaller regions with information of intended local gloss levels (c). Approach (d) of the workflow as previously shown in Figure 2(a), using one identical ICC profile for each of the sub patches, compared to workflow (e) with local selection of ICC profile based on applied gloss level shown in Figure 2(b). The measured LAB values of each of the patches as a result of using (d) are shown in (f) and those for (e) are shown in (g).*

a colour transformation is handled locally based on the applied gloss level, rather than the naïve approach of using one colour transformation for the entire image. To compare the two methods, we used a test set in the form of a Macbeth ColorChecker to evaluate the colour reproduction by comparing the intended LAB values with the printed patches. The test set contains some colours that are located outside the printer gamut, to evaluate the performance of our workflow for out of gamut colours. As indicated in Figure 3, each of the 24 patches of the colorchecker was subdivided into smaller patches that were printed with different gloss levels. For the naïve approach, the colour transformation from the LAB values to the CMY space was done globally using the absolute colorimetric lookup table from just one of the available ICC profiles (Figure 3 (d)). For our proposed method, we locally adapted the colour transformation on the applied gloss level, as shown in Figure 3 (e). As can be seen in the resulting printouts of Figure 3, our proposed method leads to smaller colour differences between patches with equally intended colour appearance and varying gloss level.

CMY printing system

First, we used a CMY prototype printing system, with the ability to locally apply different gloss levels. We applied three gloss modes (matte, low gloss, and medium gloss) with an average gloss level of respectively 3, 7 and 16 GU (measured under a 60° measurement geometry using a MG628-F2 gloss meter). Charts of around 1000 patches were printed per gloss mode with different coverage amounts of the cyan, magenta and yellow inks to obtain (version 2.4) ICC profiles.

To evaluate the accuracy of the lookup tables, the Profile Dump software from the ICC Labs software package [17] was used to perform a simulation test often referred to as "round tripping" [15]. Here a set of input LAB values is converted to the CMY space using the forward lookup table and back from the CMY space to the LAB values using the reverse lookup table to determine the colour differences inherent to the lookup tables of the profiles. For the obtained ICC profiles, the colour differences showed an average of 0.96 ΔE and a maximum colour difference of 10.19 ΔE for the colorimetric lookup table, similar to the results obtained in comparable experiments [15].

Our modified Macbeth ColorChecker was printed with a local gloss variation to obtain different gloss levels per colour patch, using 3 gloss modes of the available printing system. Using the ICCmatte, ICClow gloss, and ICCmedium gloss colour profiles corresponding to the gloss levels of the printouts, we printed the colorchecker transforming the LAB colour values to the CMY space for the whole image, according to the naïve approach (Figure 2 (a)). Here the drawback of such a naïve approach is clear, where for the case of using the ICCmatte profile for example, one would expect a better colour accuracy in the parts that are actually printed with the matte print mode in comparison to the parts that are printed with a different print mode. A fourth printout was therefore created according to the workflow of Figure 2 (b), using multiple profiles. Here, for the transformation of intended LAB colour values to the CMY space, the used ICC profile matches the print mode applied on each pixel location, thus locally adapting the ICC profile to the print mode.

The printouts were compared based on colour reproduction by calculating the colour difference between the intended colour and reproduced colour. Out of the 24 patches, 7 patches turned out to be located outside the printable gamut. The performance of each method was evaluated by both considering all patches and only the ones located inside the printable gamut. For those parts of the printouts where the ICC profile corresponds to the applied gloss level (the top right square of patches from Figure 3(c) and (d)), we observed average colour differences of 3.7 ΔE and maximum colour differences of 18 ΔE, which is comparable to similar research that can be found in literature [16]. As shown in Table 1, for the printouts that do spatially vary the gloss level, using any single profile leads to inaccurate performances, because of the applied gloss level affecting the colour. The same table shows that our multi profile method, where the colour transformation is locally adapted to the gloss mode, is able to better reproduce the intended colours. Furthermore, the last column of Table 1 shows the colour variation of the sub patches, where the intended colour was identical but the gloss level varied locally. The results show smaller colour variations when the multi profile approach is used.

CMYK printing system

We repeated the previously described experiment, now using a CMYK prototype printing system able to print a wider range of gloss levels. Here, we used 4 different gloss modes with average gloss levels of respectively 13, 18, 23 and 30 GU. We used a direct binary search (DBS) halftoning method and a multi level stochastic screening halftoning algorithm (MLH), which was expected to be more stable. Charts of around 1000 patches were printed per gloss mode for both halftoning algorithms to obtain (version 2.4) ICC profiles. Using the direct binary search halftoning method, the accuracy of the ICC profiles was simulated in the "round tripping" experiment and showed an average colour accuracy of 2.1 ΔE with a maximum of 14.2 ΔE (for the colorimetric lookup table). The accuracy of the ICC profiles for the Multi Level halftone case were slightly higher with an average colour accuracy of 1.2 ΔE and a maximum of 10.4 ΔE.

Similarly to the CMY printing system, our modified Macbeth ColorChecker was printed with a local gloss variation according to the workflow of Figure 2 (b), using multiple ICC profiles. The intended colours were compared to the resulting colours and the corresponding colour differences compared to the naïve approach, where only one single profile was used for the entire printout. The results are shown in Table 2 and show improved performance of the multi level halftoning algorithm compared to the direct binary search (DBS) halftoning method. In both cases the proposed multi profile method outperforms the use of only a single ICC profile for these printouts.

Conclusion and Discussion

Advanced printing techniques have the capabilities of (locally) controlling the gloss level of a printout. However, applied gloss levels affect the colour, which leads to inaccurate colour reproduction and colour differences that are visible around transitions between different gloss levels. We propose a solution where an colour profile for each of the available gloss modes is obtained and the ink coverage values are determined by locally selecting the corresponding profile for a given gloss level. This strategy enables the control of both the colour and the gloss in the printout and correct for colour shift due to the gloss level. Using two different prototype printers, we conducted an experiment to evaluate the colour reproduction for both the case of using one single ICC profile globally (i.e. naïve approach) and for our proposed method by locally selecting the ICC profile corresponding to the applied gloss mode in the printout. The results show an improved colour reproduction using a locally adaptive colour transformation, according to our implemented multi profile approach. Furthermore using a more stable halftoning algorithm showed to result in more accurate ICC profiles which further improves the accuracy of the colour reproduction and the performance of our proposed workflow. In future work we will conduct psychophysical experiments, to examine the performance of the proposed multi profile workflow for natural images with variant gloss.

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Table 1. Colour differences between intended and printed LAB values using 3 different ICC profiles globally, compared to the multi profile approach where the colour was managed by locally selecting the ICC profile corresponding to the applied gloss level. The ΔEab colour differences are calculated as the Euclidian distance between intended and resulted colours in the LAB colour space.

	mean and (max) colour difference of all patches	mean and (max) colour difference of in-gamut patches	mean colour difference around average value of sub patches
single profile$_{matte}$	4.5 (17.0)	3.0 (7.2)	1.67
single profile$_{lowgloss}$	4.3 (17.8)	2.6 (7.2)	1.67
single profile$_{med.gloss}$	4.1 (17.8)	2.8 (7.9)	1.65
multi profile	3.7 (18.2)	1.8 (6.3)	0.99

Table 2. Similar to Table 1, now for a CMYK printing system and evaluation of two different halftoning algorithms.

	mean and (max) colour difference of all patches	mean and (max) colour difference of in-gamut patches	mean colour difference around average value of sub patches
DBS: best performing single profile	5.0 (15.8)	3.3 (15.8)	3.3
DBS: multi profile	4.3 (16.5)	2.8 (16.4)	2.2
MLH: best performing single profile	2.7 (6.0)	1.7 (5.1)	1.6
MLH: multi profile	1.5 (3.2)	1.4 (3.2)	1.1

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