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Why a clear coating modifies halftone color prints

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Abstract

It can be easily observed that a white support printed with halftone ink layers changes color when coated with a clear layer. The color change can be explained by purely optical phenomena, for example the perception of a different amount of light scattered by the ink-matter interface if the observer is not too far from the specular direction. But color change can be also observed far from the specular direction, especially with halftone colors, where the support has not a homogeneous reflectance at the mesoscopic scale. This is due to subsurface optical phenomena investigated only recently in the case of uniformly colored support. In the present paper, thanks to an original optical model dedicated to halftone colors, we show that this subsurface phenomenon tends to increase the chance for light to meet several ink dots, therefore the chance to be absorbed.

Introduction

Everyone has experienced the fact that applying a clear coating such as varnish, film, wax, etc., on an object may modify its color, sometimes dramatically, without always being able to explain why [1-3]. Sometimes, wrongly or rightly, chemical, thermal or structural phenomena related to the coating process are evocated to explain the change of chroma and lightness. However, similar color changes are also observed when it is clear that the phenomena mentioned above are not in question: the reasons are rather to be found on the optical side, by studying how the replacement of the matter-air interface with a matter-coating interface topped by a coating-air interface modifies the way light is reflected.

The present paper does not claim that all types of supports or coatings will be addressed, attended the amazing variety of material combinations and structures that can be produced, from the simplest to the most complex. By discarding metals, porous, transparent and translucent supports, as well as thin coatings and glazes known to produce light interferences responsible for iridescence or gonio-chromatic effects, we propose to focus on the simple case where a strongly diffusing support is coated by a transparent, colorless layer, without any physical interaction between the two, except an optical contact (matching of their refractive indices in absence of air in between). This corresponds to a frequent material structure in graphical arts. Even in this simple case, various optical phenomena can occur, that we classify into two categories: the ones related with the matter-air interface, that we may qualify as "surface phenomena", and the ones related with the light propagation within the coating itself, qualified as "subsurface phenomena".

The pictures in Figure 1 illustrate the role of the two phenomena in the color change due to the coating, through the example of a printed page of magazine partially coated with a square piece of clear adhesive tape, whose contours are featured by red segments posteriorly embedded into the image.

The first picture, in Figure 1.a, highlights the surface phenomena: the picture has been taken at an angle corresponding to a specular-included reflection geometry. The main phenomenon, rather well-known, is the difference of light scattering by the air-matter interface due to different topologies of this interface in the coated and uncoated areas. The light concerned does not enter into the matter and therefore generates an achromatic light component, which is more or less pronounced according to the illumination geometry, the viewing angle, and the interface's bidirectional reflectance distribution function (BRDF). But this reflection component can also be chromatic if the matter-air interface has a wavelength-dependent optical index. This is rarely the case for clear coatings, whose index is generally a real number around 1.5, constant in the visible spectrum of light, but it is more common with

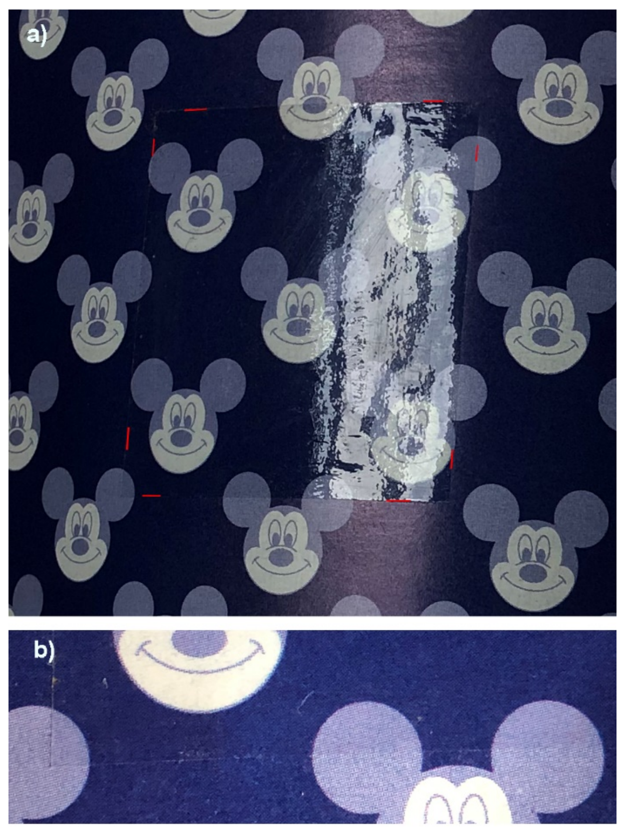

Figure 1. Pictures of a printed page of magazine [6] partially coated with a square piece of clear adhesive tape. a) Picture taken in front of a window, in specular included reflection conditions, showing the color differences due to surface phenomena; the limits of the coating are featured by red segments. b) Picture taken in specular-excluded reflection conditions on the bottom left part of the coated area, showing the color differences due to subsurface phenomena.

strongly absorbing material like inked papers, a phenomenon sometimes called bronzing [4,5]. Hence, the light component scattered by the surface is colored in absence of coating, and it is replaced with an achromatic one in presence of coating. As the tape has a rather smooth surface, it gives a glossy finishing aspect: the reflection of the window generates bright gloss patterns, rather achromatic (even though they remain slightly colored because of the diffuse light reflected by the colored support beneath the interface), with rather sharp edges. In contrast, the uncoated area has a rougher surface and produces a pale sheen with very blurry contour; this sheen looks purple in the present example, due to the bronzing effect.

Once light has crossed the air-matter interface, since the coating is clear, therefore optically neutral, light should be scattered and absorbed in a similar manner with and without coating. However, this is not what we observe on Figure 1.b, taken in specular-excluded reflection geometry, therefore in conditions where the surface phenomena mentioned above are less visible. The halftone colors are darker in the coated areas, and the halftone dots seem to be blurrier. This phenomenon has intrigued printers for a long time without a satisfactory answer having been found until now [1-3]. However, as we will show in Section 3, it seems that the subsurface scattering phenomenon recently described in [7] gives a part of the explanation. This study described how the light emitted by a given point of the diffusing support is internally reflected by the matter-air interface and reilluminates the support itself in a very specific way, i.e, under the form of a luminous ring-like halo (an example is shown later in Figure 6). This specific point spread function explains why the ink dots look blurry in the picture of Figure 1.b, and we will show that a convolutional process occurs due to the multiple reflections between the printed substrate and the air-coating interface. This increases the amount of light meeting the ink dots and thus increases the global absorbance of the halftone print, an effect that is comparable to one induced by optical dot gain in halftone prints [3].

1. Surface optical phenomena

The kind of objects that we consider in this study have the following properties: the support is strongly scattering and its point spread function (PSF) is low. When consider without its bordering interface, it is assumed to be a Lambertian reflector, i.e., it reflects same radiance in every direction of the hemisphere, whatever the illumination geometry is. It is characterized optically by an effective refractive index n_b, and an *intrinsic spectral reflectance*, or *spectral albedo*, denoted as $\rho(\lambda)$. Then, considered with its interface with air, the reflections and transmissions taking place at the interface must be considered, in a similar way as introduced by Saunderson for the Kubelka-Munk model [8]. Four parameters r_s, T_{in}, T_{out}, and r_i are introduced to represent the flux transfers at the interface, featured in Figure 2. Reflectance r_s represents the portion of

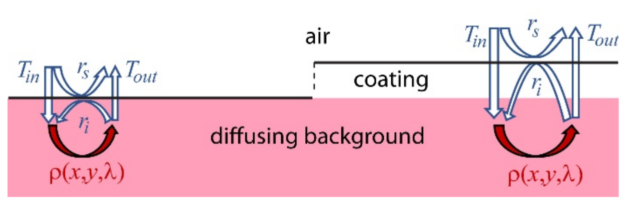

Figure 2. Cut view of a diffusing background uncoated (on the left) and coated with a clear material (on the right). NB: The arrows featuring light flux transfers have no geometrical reality.

incident light externally reflected by the interface and captured by the observer of the detector, transmittance T_{in} represents the portion of light entering into the background, reflectance r_i represents the portion of (diffuse) light internally reflected by the interface, and transmittance T_{out} represents the portion of light emerging from the background in direction to the observer or detector.

The object's reflectance factor, defined in respect to a perfectly white diffuser, is given by:

$$R(\lambda,x,y) = r_s + \frac{T_{in}T_{ex}\rho(\lambda)}{1-r_i\rho(\lambda)}. \quad (1)$$

The terms r_s, T_{in}, T_{out}, and r_i, are derived from Fresnel formulae; they depend upon the geometrical configuration for illumination and observation, as well as the relative refractive index of the interface: this latter is n_b when the background is surrounded by air, or n_b / n_c when it is surrounded by a different medium with refractive index n_c. Values for these terms have been given for example in Refs. [9,10] for a flat interface with relative index of 1.5 and various illumination-observation geometries. We can especially remind that r_s depends upon the surface roughness and can be related to its BRDF [11]. In contrast, it has been shown that T_{in}, T_{out}, and r_i remain almost independent of the surface topology [12]. Notice that Eq. (1) also coincides with the Williams-Clapper equation, originally introduced for photographic prints where a paper is coated with a layer of transparent gelatin, in the special case where the gelatin is clear, i.e., its internal transmittance is 1 [13].

Once the background is coated with the clear medium of refractive index $n_c \approx n_b$, the background-coating interface has no optical effect any more, even when its topology remains unchanged: no light reflection occurs there, and light is fully transmitted from the background to the coating and inversely. Light reflections and transmissions take place at the air-coating interface, i.e., at a distance from the background corresponding to the coating thickness (see Figure 2). The values for r_s in the coated area may differ from the ones in the uncoated area if the surface topologies in the two areas are different. This may generate slight color differences.

The fact that light travels some distance within the clear coating between the background and the air-coating interface has also no optical effect. Hence, the spectral reflectance of the support is not modified by the coating: both uncoated and coated support should have same color, if their respective values for r_s are similar. This is what we observe on the picture in Figure 3 in the band where a photo quality paper is printed with full coverage of cyan ink: the subareas without and with coating (same adhesive tape as for Figure 1), display the same color. This is also confirmed by spectral measurements: their spectral reflectance factors plotted in Figure 4, measured by using the Color i7 spectrophotometer for Xrite by discarding the specular component (de:8° geometry), are equal.

However, if we look in the specular direction, as for the picture shown in Figure 5, we see that the gloss is colored on the coated areas, whereas it is achromatic on the uncoated area (i.e., it has the color of the light source). This is due to the bronzing effect [5]: since the ink has complex refractive index varying markedly in the visible domain, the Fresnel reflection of the ink-air interface reproduces these spectral variations and produces a colored sheen around the specular direction. This latter is well visible in the picture of Figure 5, but also perceptible in Figure 1.a for a different type of ink. The spectral variations of r_s with cyan ink can be seen in Ref. [5]. Once

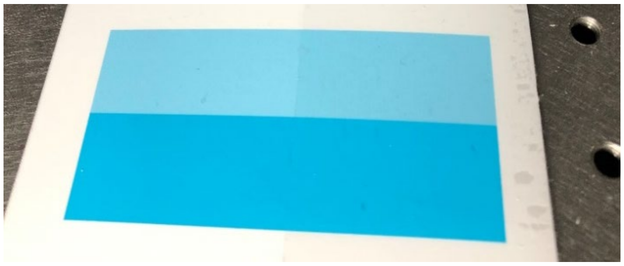

Figure 3. Picture of a glossy photoquality paper printed with two colored bands, the top one being a halftone color of cyan ink with coverage 50%, the second one being a fulltone of same cyan ink. Half of the sample, on the right, is covered with a clear adhesive tape.

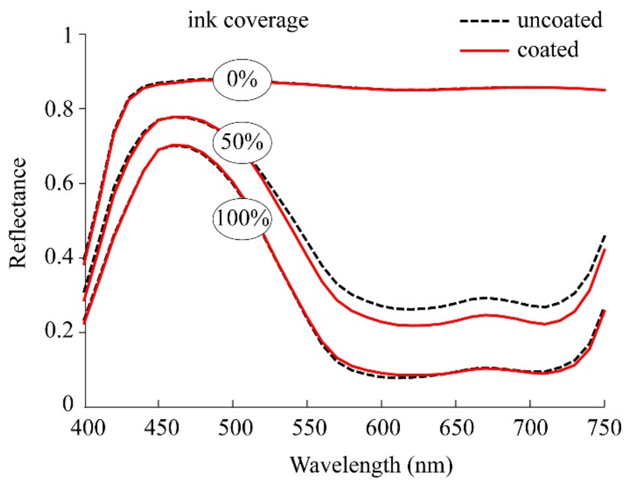

Figure 4. Measured spectral reflectance factors (de:8° geometry) of the blank support, the support printed with cyan ink (100% coverage) and the support printed with a halftone layer of cyan ink (50% coverage), in presence and absence of coating. The surfaces measured correspond to the sample displayed in Figure 3.

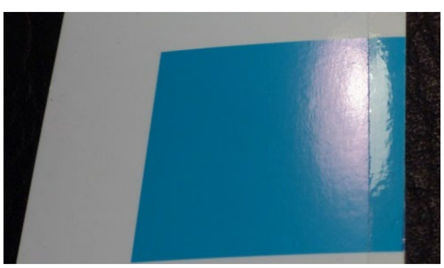

Figure 5. Photo quality paper printed with cyan ink, full coverage, partially covered by a clear adhesive polymer film (on the far right). The differences perceptible between the uncovered and covered areas are mainly due to the light reflected by the interface with air, which produces a colored pink sheen in uncovered areas, and an achromatic gloss in covered areas [5].

the print is covered with the clear tape, the ink-tape interface is much less reflecting, and the tape-air interface reproduces the achromatic reflection characteristic of dielectric materials with constant refractive index in the visible domain. Once again, this is clearly visible in the pictures of Figures 5 and 1.a, taken in the specular direction. In contrast, the picture of Figure 3 has been taken far away from the specular direction, and the light reflected by the matter-air interface is not captured (i.e., $r_s = 0$), reason why the coated and uncoated areas display the same color.

We can be surprised by the fact that the white paper in the picture of Figure 3 has different colors in the coated and uncoated areas, whereas their spectral reflectances are very similar. This is again due to the different surface topologies of the two matter-air interfaces, the nude paper being rougher. The geometry under which the picture has been taken emphasizes a difference of r_s value, whereas the geometry of the reflectance measurement does not.

In this sample, the areas printed in light cyan (halftone color of cyan ink with 50% surface coverage) with and without coating also display different colors. The color difference is even more marked than for the white paper. We could have expected that it is less pronounced since 50% of the paper surface being covered by ink and the presence of coating on the inked paper does not modifies its color. The measured spectral reflectances plotted in Figure 4 show that the difference is mainly in the spectral domain where the ink is the more absorbing, i.e., beyond 500 nm. The reason of this darkening of the halftone color in presence of coating, already noticed in the literature dedicated to printing technologies [1], is the sub-surface propagation of light that we describe in the next section.

2. Subsurface optical phenomenon

The recent work by Simonot et al. [7] has put into evidence the particular light propagation into a transparent, possibly colored but not scattering, coating in optical contact with a dif-fusing support. This is typically the situation that we meet with a printing support covered by a lamination film or a varnish with glossy finishing. When one point of the support is illuminated with a thin light pencil, the light backscattered by the support is then internally reflected by the air-coating interface and re-illuminates the support by producing a ring-like halo as shown in Figure 6.a. This is the consequence of the interface's angular Fresnel reflectance at the medium side. The illuminated point, not represented in this figure, is at the coordinates $(x, y) = (0, 0)$. Around it, a dark central disk corresponds to the area weakly reilluminated by rays whose angle is lower than the critical angle θ_c, and for which the Fresnel reflectance does not exceed 0.05. Near θ_c, the Fresnel reflectance rapidly reaches one, and all rays oriented by an angle higher than θ_c are totally reflected. This explains the high irradiance on the support beyond a certain distance from the center, and the rather sharp transition between the dark and bright areas. Every point of the support re-illuminated then generates again a similar halo, and this occurs multiple times. All halos generated during the multiple reflection process finally produce the halo shown in Figure 6.b through the picture of a white waterproof paper covered, in optical contact made by oil, by a glass plate and illuminated with a laser beam (The bright spot at the center of the image corresponds to the point on the support illuminated by the laser beam).

This halo is visible only when the illumination is punctual, a situation rather rare in the everyday life. Moreover, the halo is visible with naked eyes only if the coating is thick enough (the halo diameter being proportional to the coating thickness), e.g. several millimeters. This is probably the reason why the pheno-menon is little known. Another reason is the fact that the halo has no optical effect on the reflectance at the macroscopic scale if the support is uniformly colored, as shown previously: only the total irradiance of the support after each step of the multiple light reflection process matters (see for example the Williams-Clapper model describing this multiple reflection process in white paper support coated with a transparent gelatin layer [13]). However, when the intrinsic reflectance of the support varies along the surface as it is the case with halftone prints, the fact that light may meet different ink dots

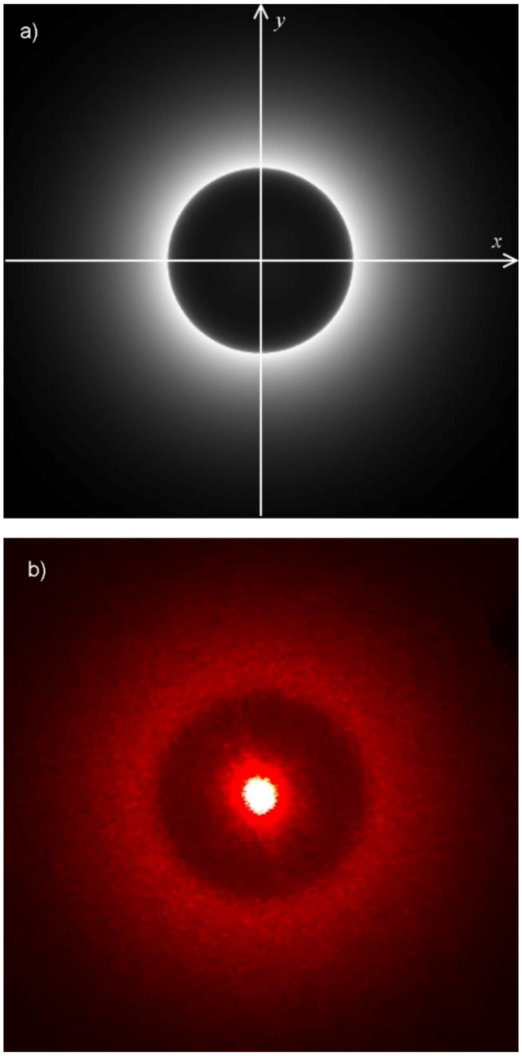

Figure 6. a) Simulation of the irradiance map produced on a diffusing support by the lambertian light issued from the central point of coordinates (0, 0) after internal reflection on the coating-air interface, as a consequence of the angular Fesnel reflectance. The diameter of the ring is proportional to the coating thickness. b) Picture of the halo observed on a paper coated with a thick glass plate illuminated at the center (bright spot) by a thin laser beam [7]. This halo results from the multiple convolution of the irradiance map shown in a) with itself.

during the multiple reflection process is of high importance. Actually, at each step of the process, the reflectance of the support, function of position of the surface, is convolved with the halo featured in Figure 6.a. The multiple convolution process, modeled below, explains why the ink dots in Figure 1.b in the coated area look blurry.

The printed support, assumed to be a Lambertian diffuser of refractive index n_b, has an intrinsic reflectance $\rho(x,y,\lambda)$ depending upon position (x,y) on the surface because of the presence of ink dot periodically placed according to a halftone screen. The reflectance is either $\rho_1(\lambda)$ in non-inked areas (coverage 1 – *a*), or $\rho_2(\lambda)$ in inked areas (coverage *a*). Most often, light transfers occur between these areas due to light scattering within the support, a phenomenon known as optical dot gain, or Yule-Nielsen effect. However, in the present paper, we assume that this effect does not occur in order to be sure that the light transfers occurring are only due to the halo effect. Preventing the Yule-Nielsen effect means that the halftone period is large compared to the point spread function of the support. Each point of the support, inked or non-inked, therefore reflects light independently of each other.

The reflectance factor of the uncoated print, taking into account the crossing of light of the interface and the multiple internal reflections as in Eq. (1), is given in each point by:

$$R(x,y,\lambda) = r_s + \frac{T_{in}T_{ex}\rho(x,y,\lambda)}{1-r_i\rho(x,y,\lambda)} \tag{2}$$

and, if viewed from a long distance, the resulting reflectance is:

$$\begin{aligned} R(\lambda) &= \frac{1}{A}\iint_A R(x,y,\lambda)\,dxdy \\ &= r_s + (1-a)\frac{T_{in}T_{out}\rho_1(\lambda)}{1-r_i\rho_1(\lambda)} + a\frac{T_{out}T_{ex}\rho_2(\lambda)}{1-r_i\rho_2(\lambda)} \end{aligned} \tag{3}$$

where *A* denotes the printed area. Remind that r_s, T_{in}, T_{out}, and r_i are wavelength-independent of as long as the refractive index of the material is constant over the visible spectrum of light.

Let us coat the print with a clear layer with refractive index 1.5 and thickness *d*, whose interface with air is smooth (it thus has a glossy aspect). The support-coating interface has no optical effect as the difference of optical indices between the coating and the support is small. The coating-air interface is smooth, and distant of *d* from the substrate. The irradiance of the substrate produced by the halo and shown in Figure 6.a, assuming that the initial irradiance at the central point is unity, is given by [7]:

$$h(x,y) = \frac{4d^2 R_{10}\left(\arctan\left[\sqrt{x^2+y^2}/(2d)\right]\right)}{\pi\left(x^2+y^2+4d^2\right)^2} \tag{4}$$

We can verify that the flux contained in the halo, divided by the flux emitted by the central point assumed to be unity, is independent of *d* and coincides with the internal reflectance r_i of the interface:

$$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h(x,y)dxdy = r_i \tag{5}$$

When the substrate is printed with a halftone pattern, the halo effect allows light transfers between inked and non-inked areas. As light paths meeting at least once inked areas are more frequent, the global absorbance of the print is increased and its color is darker. This effect is comparable to the optical dot gain due to subsurface scattering within the substrate and produces similar effect: it can be viewed as an additional dot gain, as observed in [3].

The print is uniformly illuminated. Hereinafter, we omit the dependence of wavelength in the notations. The incident irradiance, *E*, assumed to be unity, crosses the interface (transmittance T_{in}), then strikes the substrate. Each point (x,y) of the support receives same irradiance $E_0 = T_{in}E$, reemits an exitance $M_1(x,y) = \rho(x,y)E_0$ according to the local intrinsic reflectance $\rho(x,y)$, which produces a halo that re-illuminates the substrate with an irradiance defined in every point as:

$$E_1(x,y) = M_1(x,y) * h(x,y) \tag{6}$$

where symbol $*$ denotes the 2D convolution operator. Each point reemits an exitance $M_2(x,y)=\rho(x,y)E_1(x,y)$, which produces again a halo re-illuminating the substrate, and so on. The successive exitances $M_k(x,y)$ satisfy the following recursive equation

$$M_k(x,y)=\rho(x,y)\left[M_{k-1}(x,y)*h(x,y)\right] \quad (7)$$

We can show that beyond $k = 10$, the exitance $M_k(x,y)$ is close to zero and the iterative process can stop.

The total exitance $M(x,y)$ is the sum of all exitances $M_k(x,y)$, and the radiance $L(x,y)$ observed from a certain direction, after crossing the interface (factor T_{out}), is given by

$$L(x,y)=\frac{1}{\pi}T_{out}\sum_{k=1}^{10}M_k(x,y) \quad (8)$$

The reflectance factor of the coated print, as viewed from a large distance, is finally given by the average value of $L(x,y)$ over the whole surface area, divided by the radiance $1/\pi$ scattered by a perfect white diffuser in same direction and under same unit irradiance E:

$$\begin{aligned} R'(\lambda) &= r_s+\frac{\pi}{A}\iint_A L(x,y,\lambda)\,dxdy \\ &= r_s+\frac{T_{out}}{A}\iint_A \sum_{k=1}^{10}M_k(x,y)\,dxdy \end{aligned} \quad (9)$$

3. Simulations with line halftones

The deviation of the coated print's reflectance from the uncoated print's one depends on the ratio between the halftone period p and the coating thickness d. In order to illustrate this, we made simulations by considering a halftone pattern made of vertical lines, shown in Figure 7, given by the function:

$$\rho(x,y)=\begin{cases}\rho_2 \text{ when } jp\le x<jp+a \\ \rho_1 \text{ otherwise}\end{cases} \quad (10)$$

where j is any natural number in a range covering the print's width, and a is the surface coverage of the line comprised between 0 and 1.

As this halftone pattern is constant along the y-axis, one can replace the 2D convolution with a 1D-convolution with the function $H(x,y)$ given by:

$$H(x,y)=\int_{-\infty}^{\infty}h(x,y)\,dy$$

which simplifies the numerical computations while keeping intact the optical effect that we want to model.

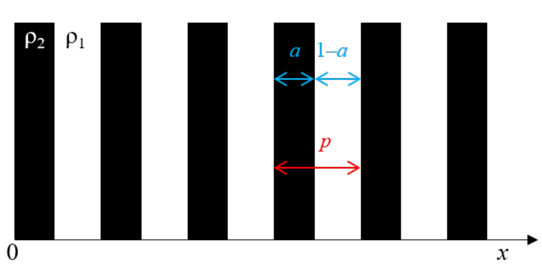

Figure 7. Line halftone pattern, with period p and surface coverage a, along which the support has two possible reflectances ρ_1 and ρ_2.

In a first simulation, we considered a halftone screen where the ink surface coverage is 0.5. The refractive index considered for the support and the coating is 1.5. The non-inked areas have a reflectance factor unity. Hence, the intrinsic reflectance of the support, very close to 1, is given by:

$$\rho_1(\lambda)=\frac{1-r_s}{T_{in}T_{ex}+r_i(1-r_s)} \quad (11)$$

Regarding the inked areas, various intrinsic reflectances ρ_2 have been considered from 0 to 1 in steps of 0.1. The reflectance factors are plotted in Figure 8 as functions of the ratio d/p, which varies over 5 decades from 10^{-4} to 10. When d/p is very small, the reflectance factors coincide with the ones of the uncoated supports given by Eq. (3). As the coating becomes thicker, i.e., d/p increases, all reflectance factors decrease, except in the case where $\rho_2=\rho_1=1$ which corresponds to a uniform substrate. When d/p reaches a few units, the reflectance factors stabilize at constant values given by:

$$R''(\lambda)=r_s+\frac{T_{in}T_{ex}\left[(1-a)\rho_1(\lambda)+a\rho_2(\lambda)\right]}{1-r_i\left[(1-a)\rho_1(\lambda)+a\rho_2(\lambda)\right]} \quad (12)$$

This equation means that the halftone dots are so small and close from each other that they form a uniform support. We can notice the similarity between this equation and the Clapper-Yule equation, which also describes light transfers between inked areas along a multiple reflections process, but this time due to subsurface scattering within the diffusing support [14].

For $\rho_2 = 0$, i.e., for the maximal contrast between inked and non-inked areas, the reflectance factor is 0.5 for a very thin coating $(d/p\to 0)$ [Eq. (3)], and 0.3 for a very thick coating [Eq. (12)], which makes a relative difference of 40%.

In a second simulation, we considered fixed intrinsic reflectance values, ρ_1 given by Eq. (11), and $\rho_2=0$, and we varied the surface coverage a from 0 to 1 in steps of 0.1. For the two extreme values of a, 0 and 1, which correspond to uniform surfaces, the reflectance factor is independent of d/p as expected. For intermediate a values, the variation according to d/p is sensible. It is maximal when a = 0.5, with a relative difference of 40% between thin and thick coatings, as said before.

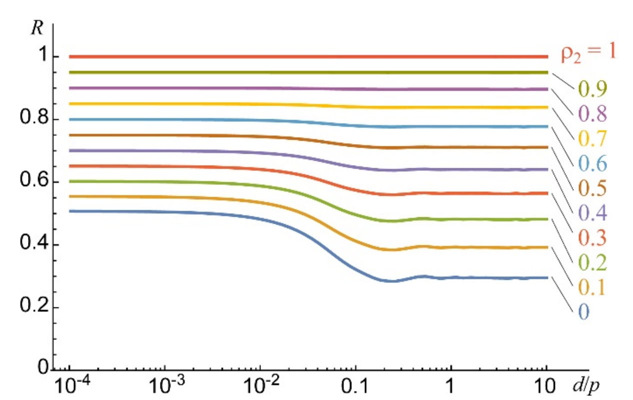

Figure 8. Simulated variation of the reflectance factors of line halftone prints with ink surface coverage a = 0.5, as functions of the ratio of the coating thickness d to the halftone period p, for a blank support of intrinsic reflectance ρ_1 given by Eq. (11) and different intrinsic reflectances ρ_2 for the inked areas (from 0 to 1, indicated by the number of the right).

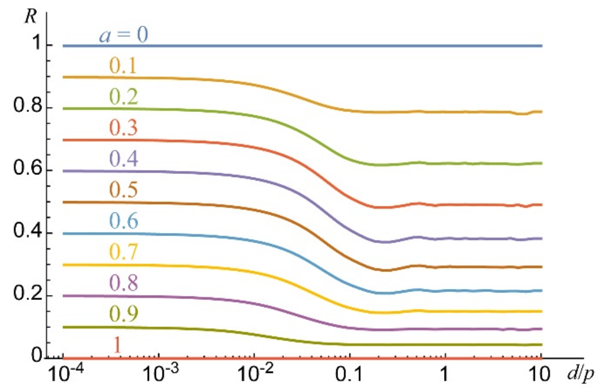

Figure 9. Simulated variation of the reflectance factor of line halftone prints with different ink surface coverages a (from 0 to 1, indicated by the numbers near the curves) as functions of the ratio of the coating thickness d to the halftone period p, for a blank support of intrinsic reflectance ρ_1 given by Eq. (11) and an inked support of intrinsic reflectance ρ_2 = 0 (perfect black ink).

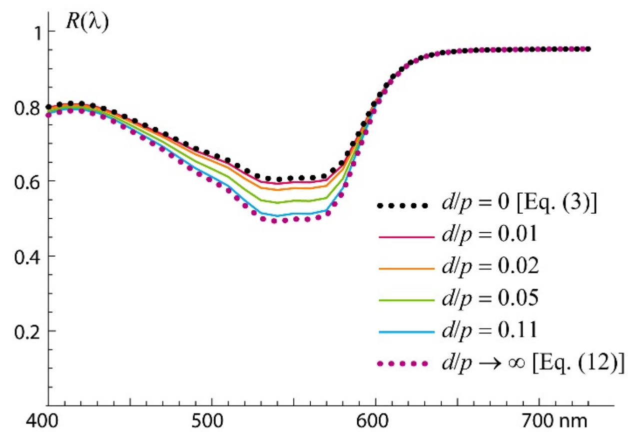

Figure 10. Simulated spectral reflectance factors of line halftone prints where a magenta ink covers 50% of the surface (a=0.5), the intrinsic reflectance value of the inked areas varying as a function of wavelength, for various coating thickness to halftone period ratios d/p.

Table 1. CIE 1976 L*a*b* color values attached to the spectral reflectances plotted in Figure 10.

d/p	*L**	*a**	*b**	*C**	*h** (°)
0	86.1	17.5	–5.9	18.4	–19
0.01	85.7	18.3	–6.3	19.3	–19
0.02	85.1	19.4	–6.9	20.6	–20
0.05	83.9	21.9	–8.1	23.3	–20
0.11	82.6	24.5	–9.4	26.2	–21
∞	82.4	25.1	–9.7	26.9	–21

Finally, we simulated the spectral reflectance line halftone prints of magenta ink with surface coverage 0.5 for various ratios *d/p*. The spectral reflectances of the blank support, $\rho_1(\lambda)$, and the inked support, $\rho_2(\lambda)$, are issued from spectral measurements on samples printed in inkjet on photo-quality paper. The case where *d/p* = 0 corresponds to the absence of coating. The support reflectance is therefore the average of $\rho_1(\lambda)$ and $\rho_2(\lambda)$ since we assume that there is no optical dot gain generated by the scattering of light in the support itself. The situation where *d/p* = 0.05 is for example met when a line haftone is printed at 12.7 lpi (period of 2 mm) and covered by a clear layer of 100 µm, or when a line halftone is printed at 127 lpi and covered by a coating of 10 µm (being aware that, as the halftone frequency increases, the Yule-Nielsen effect becomes significant and its effect adds to the halo effect). The simulated spectral reflectances, as well as the ones predicted by formulas (3) and (12), are plotted in Figure 10. The corresponding CIE 1976 L*a*b* color coordinates are given in Table 1. The simulated spectra confirm that the convolution-based model is equivalent to formula (3) when *d/p* tends to 0 (black dotted line), and it is equivalent to formula (12) when *d/p* tends to infinity (purple dotted line). They also confirm that, as *d/p* increases, the spectral reflectance decreases, especially at wavelengths for which the ink is the most absorbing (at wavelengths for which it is clear, e.g., beyond 630 nm, the coating thickness has no effect on reflectance). This variation of spectral reflectance is translated into slight decrease of lightness and increase of chroma, as shown in Table 1 by the variation of the L^* and $C^* = \sqrt{a^{*2} + b^{*2}}$ coordinates. Hue, computed as the angle $h^* = \arctan(b^*/a^*)$ in degree, remains almost constant. This is consistent with the observations reported for example in [3] for glossy varnished offset prints.

Conclusions

The present paper has shown that at least three optical phenomena can explain the color change due to application of a clear coating on a colored support. If the viewing angle is not far from the specular direction in respect to the light source, different amounts of the light scattered by the matter-air interface can be perceived according to the different surface topologies of the support and the coating. The difference concerns mainly the lightness, but also the chroma. In the same viewing conditions, if the support is strongly absorbing, its refractive index may vary according to the wavelength of light and the light scattered by the surface may generate a colored sheen (bronzing effect), which is replaced with an achromatic sheen once coated. Finally, in the case of non-uniformly colored support like halftone prints, subsurface propagation of light plays an important role: the multiple convolution of the support's reflectance, function of position, and a ring-like halo whose diameter is proportional to the coating thickness, may increase the global absorption of light by the ink dot, especially if the coating thickness is large in comparison to the halftone screen period and the ink surface coverage is around 50%. This effect can explain the decrease of lightness and increase of chroma observed when coating halftone colors with glossy finishing [3].

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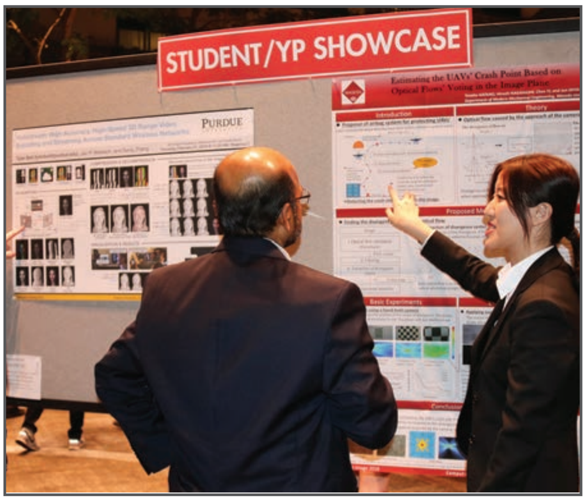

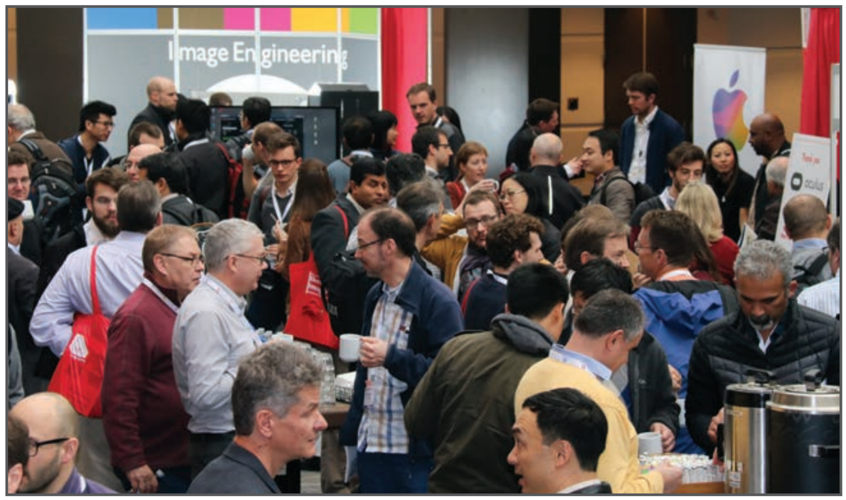

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