Journal of Imaging Science and Technology® 56(6): 060507-1–060507-7, 2012.

Assessing the Lightfastness of Prints by Image Chrominance Histogram Quantification

Silva König, Diana Gregor-Svetec, Aleš Hladnik, and Tadeja Muck
University of Ljubljana, Faculty of Natural Sciences and Engineering, Snežniška 5, SI-1000 Ljubljana, Slovenia
E-mail: silva.koenig@ntf.uni-lj.si

Abstract. *In many practical applications, printed images or text are exposed to a light source, making their lightfastness an important characteristic. Good lightfastness assures good color stability after prolonged use. In this study an accelerated aging procedure using a xenon arc lamp was applied to induce and investigate the degradation of Altona test chart color images and patches of offset and electrophotographic prints on papers made of virgin and 100% recycled fibers. In this article the authors present a new image processing method based on chrominance histogram quantification and discuss its applicability and performance with respect to the conventional spectrophotometric approach. The chrominance histogram quantification method using printed images proves to be a viable alternative to the established spectrophotometric measurements that are implemented on color patches and yield 2D color gamut information.© 2012 Society for Imaging Science and Technology.*
[DOI: 10.2352/J.ImagingSci.Technol.12.56.6.060507]

INTRODUCTION

According to Wilhelm,[1] standardized image permanence tests serve a number of important purposes. First, they can provide guidance to consumers who want to select the longest-lasting materials that otherwise meet their needs in terms of cost, image quality, print size, and convenience. Second, these methods help graphics research departments to evaluate and improve the longevity of future products. Third, they provide manufacturers with image permanence data while supplying the information to customers as part of general product specifications. These tests also assist museums and archives in estimating the stability properties of the imaging materials in their collections so that proper storage and display conditions can be implemented to achieve long-term preservation of the materials.

The most common environmental factors for which standardized accelerated image permanence testing methods have been developed are light, heat, humidity, and air pollutants, such as ozone.[2] ISO 5630[3,4] standards describe moist heat and dry heat treatments which are appropriate for accelerated aging of paper substrate. The ISO 18909[5] standard describes methodologies for estimating the natural aging of color photographic images with respect to either prolonged heat or light exposure.[2] ISO 18936,[6] ISO 18941,[7] and ISO 18946[8] are new photographic standards describing thermal stability, ozone gas fading stability, and humidity fastness, respectively.

In practice, prints are commonly exposed to a light source, making their lightfastness an important characteristic. Good lightfastness assures good color stability after prolonged use. Accelerated aging by the Xenotest method in a light chamber is performed when the influence of light on a material needs to be determined. The ISO 12040[9] standard describes the assessment of lightfastness using filtered xenon arc light. The lightfastness of a print depends on the exposure conditions (e.g., time, intensity, and spectral power distribution of the light source), substrate, and ink layer thickness, but primarily on the characteristics of the colorants. If these factors are not adequate, the color of the print will fade, its chroma or hue will change, and eventually its color can disappear altogether.[10,11]

Estimation of the degree of printed sample degradation is most commonly performed based on densitometric or spectrophotometric measurements.[12–14] Wilhelm Imaging Research provides the WIR i-Star software designed to evaluate the reproduction accuracy (i.e., retention of color, lightness, contrast) of a reproduced/altered image with respect to a reference image. It can also be used for image permanence studies, where the software calculates a series of results for a number of images representing the same photographic print over time and visualizes the loss of accuracy as the print ages.[15] Havlinova et al.[16] investigated the stability of offset inks on paper upon aging by implementing moist heat and dry heat techniques and measuring changes in optical density and color difference, and applying visible and FT-IR spectroscopy. Oldfield et al.[17] correlated densitometric changes of aged prints to the psychophysical assessment. Černič et al.[18] assessed differences before and after moist heat aging also using print characteristic curve and surface and optical property measurements. Rat et al.[19] examined the colorimetric and typographic properties of heat and moisture treated prints. Bolanca et al.[20] compared the 2D color gamuts of moist heat and natural aged prints where the primary and secondary colors were visualized in the CIE a^*b^* diagram. Determination of 3D color gamut volume, where the third component—lightness L^*—is also taken into account, was used for degradation estimation too. Several researchers have demonstrated that the color gamut volume and its shrinking during fading can provide useful information on print permanence. The relative gamut volume change during aging can be expressed as a single number,

Received Aug. 28, 2012; accepted for publication Feb. 14, 2013; published online Mar. 26, 2013.
1062-3701/12/56(6)/060507/07/$20.00

Figure 1. Altona test form images "Fruit" (left) and "Egg" (right).

thus conveniently quantifying the process of dye fading.[21,22] The lightfastness of both traditional silver halide-based and modern inkjet photographic media has been investigated.[23] Majnaric et al.[24] analyzed the diameters of the smallest achromatic printing elements (black halftone dots of 10%, 20%, and 30% raster tone value) by means of microscopic image analysis. The results showed that moist heat aging caused a decrease in the size of the printed halftone dots.

In addition to using a spectrophotometer to obtain CIE $L^*a^*b^*$ values of test chart color patches, one can also employ printed images to estimate the lightfastness of prints, i.e., resistance to accelerated aging conditions. The purpose of the present research was to compare the applicability and performance of a recently developed color image processing method, based on chrominance histogram quantification of the printed image (see the section *Materials and Methods*), with those of the established spectrophotometric procedure where color patches are measured.

MATERIALS AND METHODS

In this research, four different commercially produced papers were tested. The Slovenian paper mill Papirnica Vevče supplied two wood-free papers: uncoated (VUP) and matt-coated (VCP) papers made of virgin fibers. The other two papers were bought from the Danish paper manufacturer Dalum Papir A/S. These papers were 100% recycled, uncoated (RUP) and matt-coated (RCP). All papers are primarily designed for offset printing; however, they are also suitable for some general office applications.[25]

All papers were printed by a sheet-fed offset printing machine, Komori Lithrone S29, and an electrophotographic printer, HP Indigo 3550 Digital Press. The former printer uses conventional offset inks, Diatone Ecopure SP (Sakata inx Espana, S.A.), while the latter one employs liquid toners, Electroinks (Hewlett-Packard Development Company, L.P.). The four process color inks were cyan (C), magenta (M), yellow (Y), and black (K). The printed test chart comprised primary (C, M, Y) and secondary (R, G, B) solid color patches and images from Altona Test Suite—Altona Visual 1.2a[26] (Figure 1). Two elements of the test form, one with vivid, saturated colors—the image referred to as "Fruit"—and another with low key, brownish colors—the "Egg" image—were used for further analysis.

Xenotest Alpha (Atlas) was used for the lightfastness treatment. The specimens were exposed to a xenon arc light at a temperature of 35°C with 35% relative humidity. The temperature of the black standard was 50°C. A Xenochromo 320 nm filter and turning mode illumination with an irradiation intensity of 42 W m^{-2} were used.

"Fruit" and "Egg" images before and after the accelerated aging procedure (6 and 12 days) were acquired by an Epson Perfection 4990 Photo scanner at 600 dpi resolution and 48-bit HDR bit depth. The scanned images were converted into a digital form. Using the MATLAB® code[27,28] (see appendix) the chrominance histogram for each of the color images was constructed, visualized, and quantified. The procedure involved several steps, as depicted in Figure 2.

First, a true color, 24-bit RGB image was converted into CIE $L^*a^*b^*$ color space, which makes it possible to separate the perceived lightness, i.e., luminance L^*, from the chrominance (hue and saturation, represented by a^* and b^*) components. Next, a 2D histogram of a^* and b^* values was created. Each color in the original image was represented by a pair of a^*b^* values in the histogram plot; the brighter the particular pixel of the histogram object, the larger the number of original image pixels having the corresponding chrominance. Next, the grayscale object was converted into a binary one by intensity thresholding. The threshold (T) was set to the value of 0: the pixels of objects with intensity $> T$ became foreground (black in Fig. 2) pixels whereas pixels whose intensity was zero were set to background. In other words, all occurrences of a^*b^* pairs that appeared at least once in a particular color image were taken into account (detected). Finally, the area of the object in the binary image (A) was computed by counting the number of foreground pixels.

RESULTS

Primary and secondary color patches of prints before and after the Xenotest treatment were analyzed spectrophotometrically.[12] These results are presented as 2D color gamuts in Figures 3 and 4. The calculated areas for the corresponding 6-color (RGBCMY) a^*b^* polygons (CG area) are given in Figure 5.

Images and a^*b^* plots generated during the implementation of the chrominance histogram quantification method for the images of "Fruit" before and after 12 days of Xenotest treatment using one particular printer/substrate combination, namely Offset/VUP, and $T = 0$ are shown in Figure 6. The number of foreground pixels (A) with $T = 0$ (area computation in Fig. 2) is given in Figure 7. It should be noted that when choosing a higher threshold value, the number of foreground pixels and, consequently, the object area is smaller, but the trends are very similar to those for $T = 0$.

The relationship between the two methods used for the lightfastness assessment of our prints—spectrophotometric-based determination of the color patches' 2D gamut areas ("Delta CG area") and chrominance histogram quantification of "Egg" ("Delta A—Egg") and "Fruit"

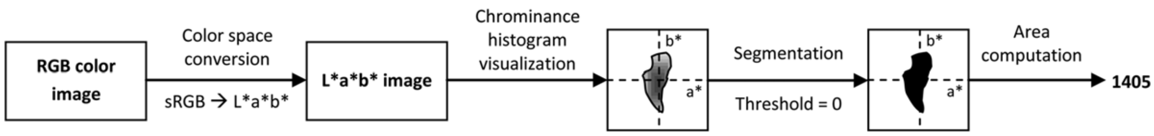

Figure 2. The color image processing workflow applied for chrominance determination. See the text for an explanation.

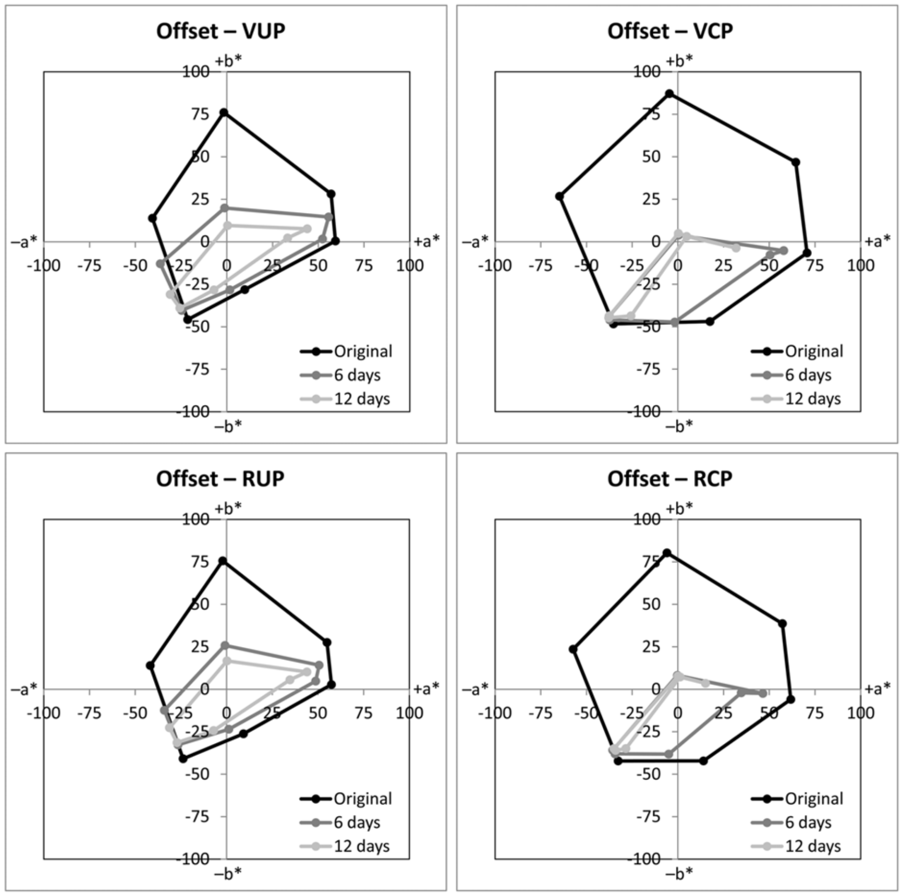

Figure 3. 2D color gamuts for color patches of offset prints.[12]

("Delta *A*—Fruit") images—can be deduced from the two scatter plots displayed in Figure 8. Each data point (printer–substrate–aging days) in the two diagrams denotes the difference in CG (or *A*) values between the non-aged ("Original") and aged samples after 6 or 12 days of Xenotest treatment. "OF" and "EL" denote offset and electrophotographic printers, respectively. The coefficient of determination (R^2), i.e., the Pearson correlation coefficient squared, displayed next to each regression line, provides the strength, i.e., magnitude, of the linear correlation between the two methods.

DISCUSSION

Fig. 5 shows that the electrophotographic prints of the color patches possess a much better lightfastness compared to the offset prints. Of the remaining two manipulated variables—paper coating and fiber type—the former has in general a more pronounced effect on the lightfastness of printed patches: offset prints on coated papers (VCP, RCP) exhibit a poorer lightfastness when compared to that of uncoated papers (VUP, RUP). The effect of the fiber type within each group is comparatively lower. With electrophotographic prints the trends are similar, although the situation is more complicated and is also influenced by the duration of the accelerated aging procedure (6 or 12 days).

The results of the chrominance histogram quantification method for both images (Fig. 7) are similar to the 2D gamut areas discussed above, with some important differences. First, for the prints produced with the offset printer, the "Fruit" image seems to yield results that correlate better with the color gamut calculations (Fig. 5) than the "Egg" image results: the image lightfastness for the coated paper pair VCP–RCP is lower after both 6 and 12 days than that for the substrates VUP and RUP, similarly to what was observed for the corresponding printed patches. This similarity is even more evident if one inspects the values for the CG area (Fig. 5) and the *A* values (Fig. 7) for both 12

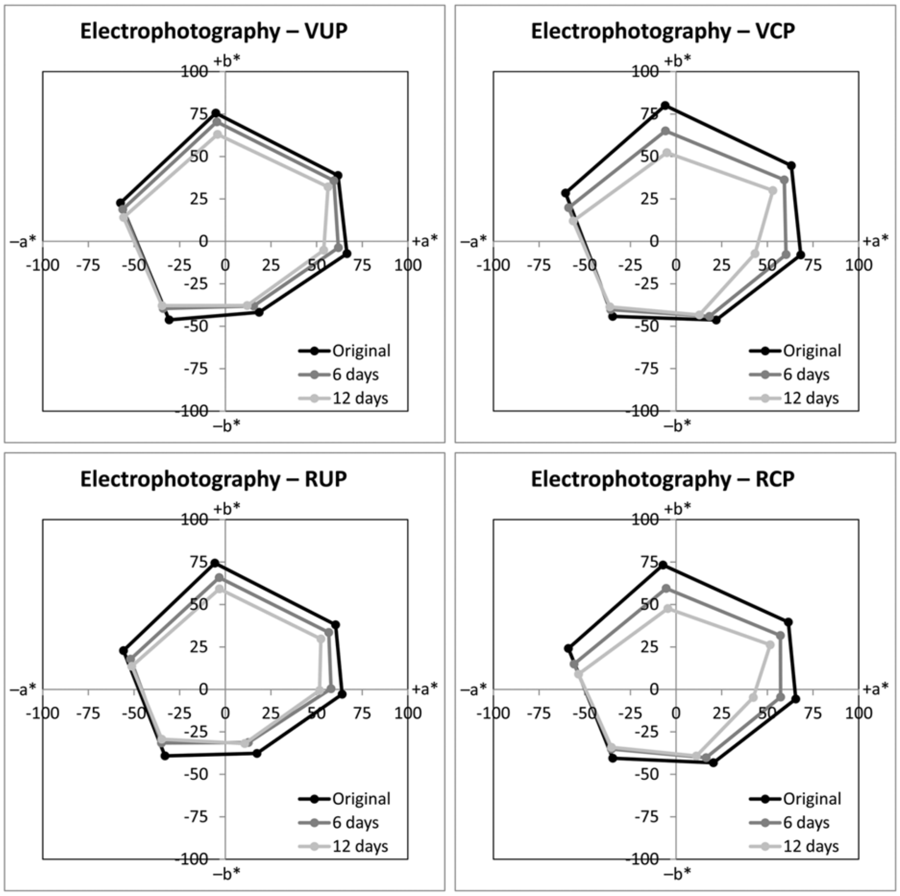

Figure 4. 2D color gamuts for color patches of electrophotographic prints.[12]

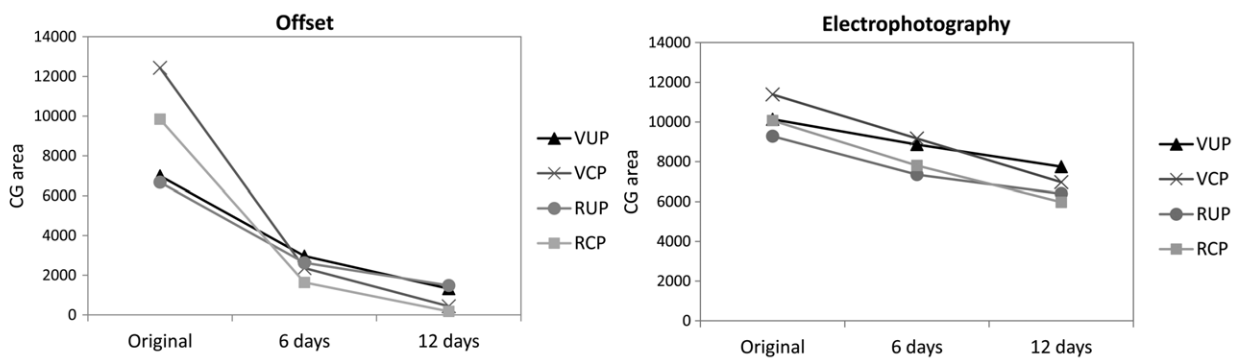

Figure 5. Calculated 2D color gamut areas of printed color patches.

days aged printed images. Second, the results for the "Egg" image printed with the electrophotographic printer provide very little discrimination between the VCP–RCP pair—or between the VUP and RUP prints—while the "Fruit" image diagram bears more resemblance to the printed patches' diagram (Fig. 5).

Further evidence that the "Fruit" image is more suitable for gamut calculation purposes than the "Egg" image is illustrated in Fig. 8. A higher R^2 value in the case of the "Fruit" image (0.97) with much larger hue, saturation, and lightness ranges compared to the "Egg" image (0.94) leads to the conclusion that saturated, colorful images should be selected when using the chrominance histogram quantification method for the assessment of lightfastness of prints.

Unlike the 3D color gamut determination procedure, requiring a large number of color patches, the chrominance histogram method uses real printed images to assess the chrominance gamut, where the size of the image can be small enough to fit into any accelerated aging chamber.

The newly developed method certainly has its limitations. Since one of the three components that comprise the color of an image—the luminance—has been discarded during the calculation process, the method is less accurate

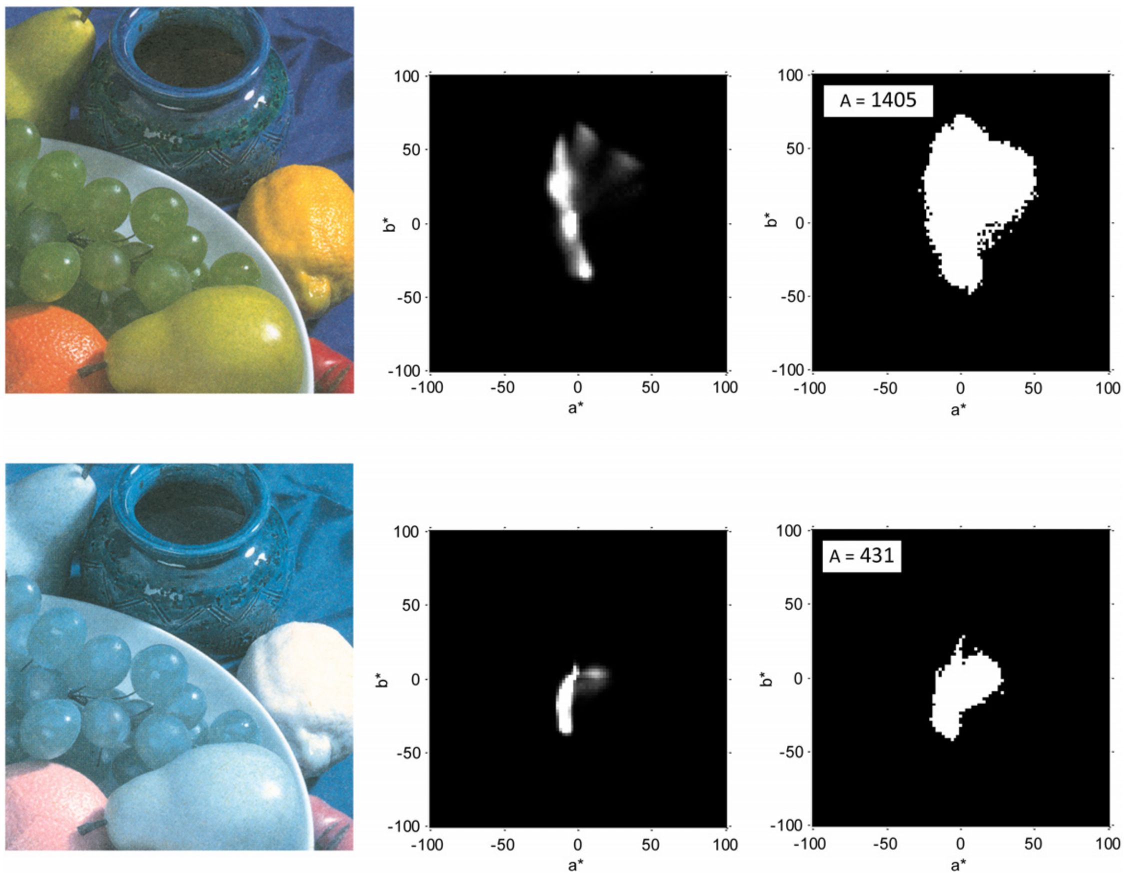

Figure 6. Images and plots generated by applying the chrominance histogram quantification workflow. "Fruit–Offset–VUP" image before (top left) and after 12 days of accelerated aging (bottom left), corresponding grayscale histograms (middle) and binary histograms obtained after segmentation with $T = 0$ (right).

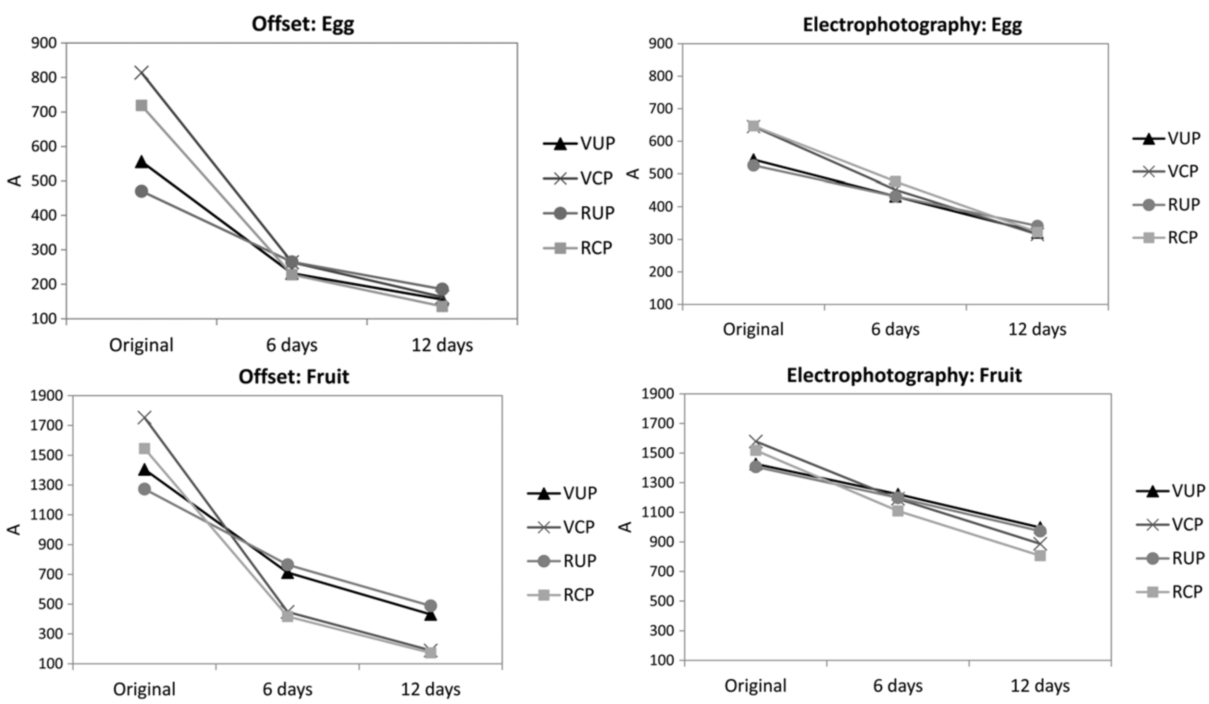

Figure 7. Chrominance histogram method: number of foreground pixels (A) with $T = 0$.

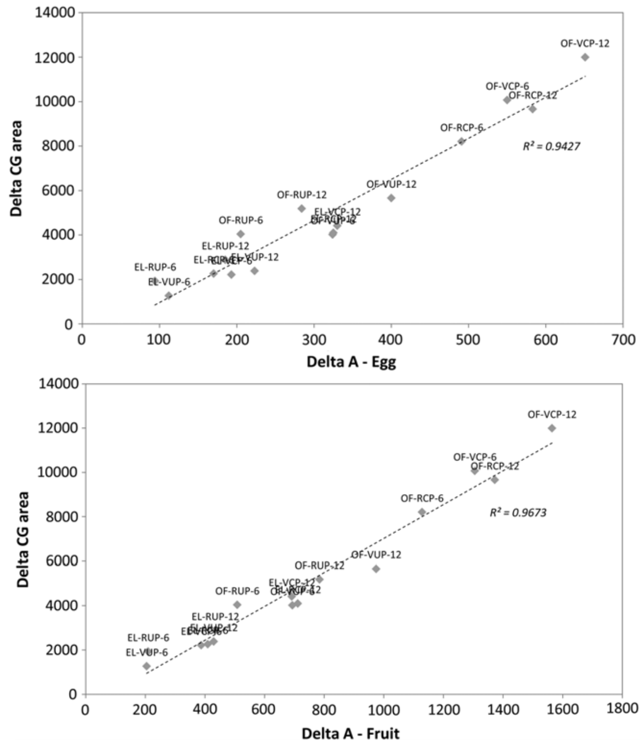

Figure 8. Scatter diagrams showing the linear relationships between the color gamut (CG) and chrominance histogram (A) quantification results for the images "Egg" (top) and "Fruit" (bottom).

than the 3D color gamut calculations that take into account all three color attributes. On the other hand—apart from a single number capturing the magnitude of the image chrominance—the size, location, and shape of the chrominance "body" (Fig. 6) generated by our method contain important information about the hue and saturation changes that can take place due to varying experimental conditions, such as accelerated aging or printer type. For instance, the a^*b^* histogram plots in Fig. 6 depict a strong reduction in the yellow color of the original "Fruit" image due to the Xenotest action.

CONCLUSIONS

The preliminary results with the recently developed method presented in this article are promising. Whenever information on the luminance of the printed images is of lesser importance and can be neglected, the chrominance histogram quantification method provides a convenient and easy way of predicting the degree of print quality degradation due to environmental factors such as light, moisture, or heat. Under these conditions, the method proved to be a viable—and faster—alternative to the conventional spectrophotometer-based procedure which uses color patches to determine the 2D a^*b^* color gamut of a print. In further research we will focus on comparison of the method with 3D color gamut assessment procedures and on its evaluation using various objective image quality metrics.

ACKNOWLEDGMENT

The financial support for the Ph.D. grant from the Slovenian Research Agency is gratefully acknowledged.

Appendix

The MATLAB® code for the chrominance histogram quantification method producing results shown in Fig. 6, top:

```
% Preprocessing steps
name = ('Fruit-Offset-VUP.tif');
rgb = imread(name);
figure, imshow(rgb);
lab = applycform(rgb, makecform('srgb2lab'));
lab = lab2double(lab);
a = lab(:, :, 2);
b = lab(:, :, 3);
N = 101;
bin_centers = linspace(−100, 100, N);
subscripts = 1 : N;
ai = interp1(bin_centers, subscripts, a, 'linear', 'extrap');
bi = interp1(bin_centers, subscripts, b, 'linear', 'extrap');
ai = round(ai);
bi = round(bi);
ai = max(min(ai, N), 1);
bi = max(min(bi, N), 1);
acc_arr = accumarray([bi(:), ai(:)], 1, [N N]);
xdata = [min(bin_centers), max(bin_centers)];
ydata = xdata;

% Visualization of a*b* color plane
figure, imshow(acc_arr, [0 1000], 'InitialMagnification',
300, ... 'XData', xdata, 'YData', ydata)
xlabel('a*'), ylabel('b*')
axis xy, axis on

% Thresholding the acc_arr image
mask = acc_arr > 0;
figure, imshow(mask, 'InitialMagnification', 300, ...
'XData', [−100 100], 'YData', [−100 100])
xlabel('a*'), ylabel('b*')
axis xy, axis on

% Calculating A
num_pix = sum(mask(:))
```

REFERENCES

[1] H. Wilhelm, "A review of accelerated test methods for predicting the image life of digitally-printed photographs—Part II," *Proc. IS&T's NIP20: Int'l. Conf. on Digital Printing Technol.* (IS&T, Springfield, VA, 2004), pp. 664–669.

[2] D. Bugner, J. LaBarca, J. Phillips, and T. Kaltenbach, "A survey of environmental conditions relative to the storage and display of photographs in consumer homes," J. Imaging Sci. Technol. **50**, 309 (2006).

[3] ISO 5630/3–1996, Paper and board: Accelerated ageing—Part 3: Moist heat treatment at 80°C and 65% relative humidity (ISO, Geneva), www.iso.org.

[4] ISO 5630/1–1991, Paper and board: Accelerated ageing—Part 1: Dry heat treatment at 105°C (ISO, Geneva), www.iso.org.

[5] ISO 18909–2006, Photography: Processed photographic colour films and paper prints—Methods for measuring image stability (ISO, Geneva), www.iso.org.
[6] ISO 18936–2012, Imaging materials: Processed colour photographs—Methods for measuring thermal stability (ISO, Geneva), www.iso.org.
[7] ISO 18941–2011, Imaging materials: Colour reflection prints—Test method for ozone gas fading stability (ISO, Geneva), www.iso.org.
[8] ISO 18946–2011, Imaging materials: Reflection colour photographic prints—Method for testing humidity fastness (ISO, Geneva), www.iso.org.
[9] ISO 12040–1997, Graphic technology: Prints and printing inks—Assessment of light fastness using filtered xenon arc light (ISO, Geneva), www.iso.org.
[10] M. Debeljak and D. Gregor-Svetec, "Optical and color stability of aged specialty papers and ultraviolet cured ink jet prints," J. Imaging Sci. Technol. **54**, 060402–1 (2010).
[11] R. H. Leach and R. J. Pierce, *The Printing ink Manual* (Kluwer Academic Publishers, Dordrecht, Boston, London, 2008), pp. 11–12.
[12] S. Grilj, T. Muck, and D. Gregor-Svetec, "The ageing resistance of offset and electrophotographic prints," Nord. Pulp Paper Res. J. **27**, 739 (2012).
[13] A. Hladnik, M. Cernic, and V. Bukosek, "Role of paper coating pigments and additives in darkfastness of ink jet prints," J. Imaging Sci. Technol. **52**, 010507–1 (2008).
[14] D. Bugner, R. Van Hanehem, M. Oakland, P. Artz, D. Zaccour, and R. Levesque, "Ozone concentration effects on the dark fade of ink jet photographic prints," J. Imaging Sci. Technol. **49**, 317 (2005).
[15] Wilhelm Imaging Research, Inc., WIR i-Star Professional User Guide, http://wilhelm-research.com/istar/manual/WIR_iStar_User_Guide_2010_01_01.pdf, accessed December 2012.
[16] B. Havlinova, D. Babiakova, V. Brezova, M. Durovič, M. Novotna, and F. Belanyi, "The stability of offset inks on paper upon ageing," Dyes Pigm. **54**, 173 (2002).
[17] D. J. Oldfield, G. Pino, R. K. Segur, S. F. Odell, and J. P. Twist, "Assessment of the current light-fade endpoint metrics used in the determination of print life—Part I," J. Imaging Sci. Technol. **48**, 495 (2004).
[18] M. Černič, J. Dolenc, and L. Scheicher, "Permanence and durability of digital prints on paper," Appl. Phys. A—Mater. Sci. Process. **83**, 589 (2006).
[19] B. Rat, K. Možina, S. Bračko, and A. Podlesek, "Influence of temperature and humidity on typographic and colorimetric properties of ink jet prints," J. Imaging Sci. Technol. **55**, 050607–1 (2011).
[20] Z. Bolanca, M. Milkovic, and I. Bolanca, "The permanence of conventional and digital offset prints," *AIC 2004 Color and Paints, Proc. Interim Meeting of the Int'l Color Assn.* (Brazilian Color Association, Porto Alegre, 2005), pp. 163–166.
[21] M. Vesely, P. Dzik, and S. Kačerova, "Optical density vs. gamut volumes for image lightfastness evaluation—an experimental study," *Proc. 14th Int'l. Conf. on Printing, Design and Graphic Communications Blaž Baromić* (University of Zagreb, Faculty of Graphic Arts, Zagreb, 2010), pp. 27–35.
[22] V. Chovancova, P. D. Fleming III, P. Howell, and A. Rasmusson, "Color and lightfastness performance of different Epson ink sets," J. Imaging Sci. Technol. **49**, 652 (2005).
[23] P. Dzik, M. Vesely, and E. Štepankova, "Comparative study on the lightfastness of traditional and modern inkjet photographic output media," *Proc. 14th Int'l. Conf. on Printing, Design and Graphic Communications Blaž Baromić* (University of Zagreb, Faculty of Graphic Arts, Zagreb, 2010), pp. 88–97.
[24] I. Majnaric, Z. Bolanca, and I. Bolanca Mirkovic, "The influence of the accelerated ageing on the black screen element of the Electroink prints," J. Phys.: Conf. Ser. **231**, 012018 (2010).
[25] S. Grilj, T. Muck, A. Hladnik, and D. Gregor-Svetec, "Recycled papers in everyday office use," Nord. Pulp Paper Res. J. **26**, 349 (2011).
[26] European Colour Iniciative, http://www.eci.org/en/downloads, accessed February 2011.
[27] S. Eddins, Two-dimensional histograms, http://blogs.mathworks.com/steve/2010/12/23/two-dimensional-histograms, accessed May 2012.
[28] S. Eddins, More on segmenting in a^*–b^* space, http://blogs.mathworks.com/steve/2011/02/04/more-on-segmenting-in-a-b-space, accessed May 2012.