Perceptual Color Contouring Detection and Quality Evaluation using Scanners

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Abstract

Within color reproduction issues, the reproducible color gamut and color accuracy can be classified as *degree zero* problems with no interaction among neighboring pixels. Image color contouring, on the other hand, occurs when perceived local color change exceeds a threshold such that observers perceive unnatural color discontinuity. Therefore, it is the color correlation within neighboring pixels that determines the existence of color contouring artifact. In this proposal, the objective is to adopt a color flatbed scanner as the measuring device to obtain color as well as spatial information. A set of test targets with smooth geometrical color variation covering various cross sections in the color space are created and printed on different printing systems. Finally, an algorithm to identify the location color contouring is proposed.

1. Introduction

Within color reproduction issues, the reproducible color gamut and color accuracy can be classified as *degree zero* problems with no interaction among neighboring pixels. Image color contouring, on the other hand, occurs when perceived local color change exceeds a threshold such that observers perceive unnatural color discontinuity. In any printing system, color contouring artifact will appear if there exists insufficient color resolution. Depending on how the system deploys its color mapping algorithm, color contouring artifact might occur in different locations within its color gamut. Therefore, it is the color correlation within neighboring pixels that determines the existence of color contouring artifact. Hence, this can be attributed as a *degree one* problem.

In this proposal, the objective is to adopt a color flatbed scanner as the measuring device. Because the reported *RGB* value is device dependent and visually nonuniform in terms of color difference, it is imperative to first transform to a visually more uniform color space (in this case, the *CIE Lab*) before analyzing color contouring. For color difference measurement, *CIEDE2000* will be adopted to better match with human perception [1]. Unlike the spectrophotometer, which is very difficult to use in term of measuring color in a global and continuous manner, by first calibrating the scanner and converting the *Scanner-RGB* device color data into *CIE Lab* color space , we hope to obtain the entire device-independent color distribution in the spatial domain to facilitate the color contouring analysis. Obviously, the color mapping precision is very important. However, since we are dealing with a *degree one* problem, the smoothness constraint on the mapping function is also essential so as not to introduce fictitious color contouring during the color mapping process. Two test targets proposed by W1.1 Image Quality Technical Committee and the *IT8.73* target with 928 patches are adopted as a training and verification data sets for scanner calibration [2]. As noted previously, color contouring might happen at various locations within the color gamut of that printing system. As a result, color ramps consisting of primary colorants of that system might be insufficient to identify those locations. The target consisting of two hexagons which cover the outside color surface is adopted in this study, and we will show that it is much easier to locate color contouring artifacts via this test target.

Figure 1: *Hexagon Target*

Once the hexagon target is scanned, an image processing algorithm is used to first take out the screen from the scanned image, and then identify the pixels at the vertices of two hexagons. These vertices will be used as reference points such that the spatial locations of the color contouring artifacts can be translated back to the device color space of the printing system. Finally, we will propose a contour detection algorithm applied on the descreened scanned image.

2. Scanner Calibration

It is well known that most of the color flatbed scanners are not colorimetric scanners. Hence, inevitably, there exist metameric colors between the chosen scanner and the colorimetric device [3,4]. That is, the accuracy of the designed color mapping function $M_s(r, g, b) \rightarrow (L^*, a^*, b^*)$ is limited by this constraint. Nonetheless, the requirements for $M_s(r, g, b)$ in the color contouring analysis are two folded: preserve the color difference across color contour, and avoid creating color contouring artifacts which are absent from the original print samples. These constraints imply that $M_s(r, g, b)$ needs to reach a balance between accuracy and smoothness. As a result, although the flatbed scanner equipped with a color mapping function can not replace the colorimetric device in terms of accuracy, it is still applicable in analyzing perceptual color contouring in a device independent manner if the above criteria are met.

Figure 2: *W1.1 Macro V9*

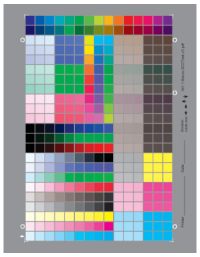

Figure 3: *W1.1 Macro V3*

Figure 4: *IT8.73 target with 928 patches*

Target as shown in Figure 2 to 4 are adopted as training and test sets, where *W1.1 Macro CMYK V9* test target is used to construct $M_s(r, g, b)$, and *W1.1 Macro Test V3* and *IT8.73* test targets are used to verify its generalization capability w.r.t. mapping accuracy. More importantly, it is necessary to verify the smoothness of $M_s(r, g, b)$ by applying it to a scanned descreened hexagon image. It should produce no spurious contouring artifact. Only mathematical regression techniques are adopted to construct $M_s(r, g, b)$ because the physical information regarding the spectral responsitivities of the scanner light sources is usually unavailable. Multidimensional polynomial regression and feedforward neural network are two most common techniques. The smoothness constraint is explicitly enforced in the polynomial regression by limiting to a lower degree polynomial, but it can only be implicitly applied via limiting the number of hidden neurons. We determine that a degree-two three-dimensional polynomial with all cross terms is the simplest function form achieving satisfactory color mapping accuracy; Hence, it is chosen as the regression model based on the Occam's Razor principle. A feedforward neural network with one hidden neuron layer and the Conjugate Gradient training method is selected and compared with the polynomial regression technique [5].

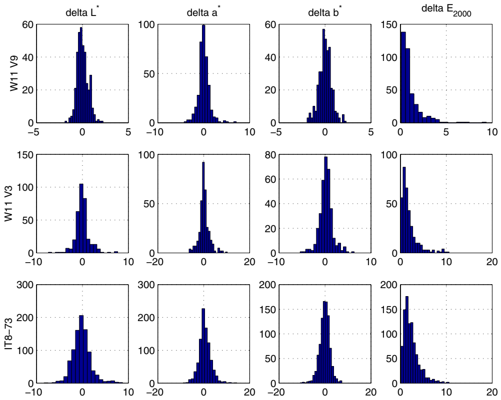

Figure 5: *Neural Network with 300 hidden neurons*

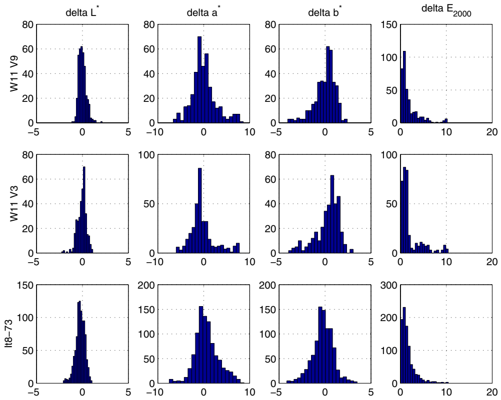

Figure 6: *Quadratic Polynomial with all cross terms*

Figure 5 and 6 show that these two mapping function have comparable mapping accuracy. However, Figure 7 and 8 demonstrates that the quadratic polynomial mapping function has better performance in terms of not creating spurious color contouring artifacts. Hence, we will adopt it in the following analysis.

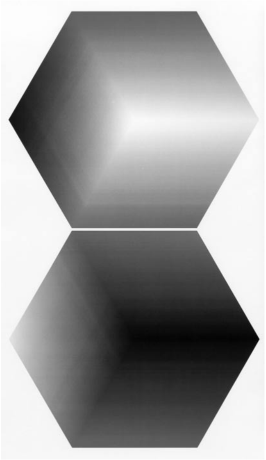

Figure 7: *Predicted L^* via quadratic polynomial fit*

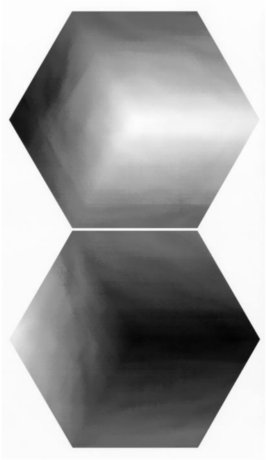

Figure 8: *Predicted L^* via neural net fit*

3. Image Preprocessing

The image preprocessing stage consists of two processes: image descreening and vertex identification. The ordinary descreening techniques intend to keep all of the image information except screen. However, the objectives of descreening scanned images for color contouring analysis is not only eliminating screen but also perceived grain because color contouring belongs to the macro image quality domain. Assuming that the scan resolution is r *dpi* and the viewing distance is d *meter*, Equation 1 is used to transform the spatial frequency from *cycle/m* to *cycle/degree*, which is used to represent the contrast sensitivity function of human beings:

$$f = \frac{2rd\tan(0.5^o)}{0.0254}. \qquad (1)$$

Based on the common practice of scanning an image at three times the screen frequency to avoid possible $Moir\grave{e}$ pattern, the highest spatial frequency captured in the scanned image is approximately 52 $cycle/degree$ assuming the viewing distance is 25 cm and 600 dpi scanning resolution. The contrast sensitivity function peaks at approximately 5 $cycle/degree$, and decays exponentially toward high frequencies [6]. We first apply the two level discrete wavelet transform using the Daubechies 9/7 biorthogonal filterbank, which is the default filterbank in *JPEG2000*. The approximation image on the level two wavelet transform contains signals with spatial frequencies up to 13 $cycle/degree$. We can assume that signals with frequencies higher than that, including screen, do not contribute to perceived color contouring artifacts. Hence, we can achieve our objectives of descreening and eliminating high frequency noise by only extracting this subband image for future color contouring analysis.

Once color contour is detected, the immediate question should be at what device color space color locations that contouring artifacts occur. Because most printing systems use four or more colorants, the inverse mapping from *CIE Lab* to device color space is usually not unique. Hence, simply indicating the locations in the *CIE Lab* space where contouring occurs does not answer that question. Recognize that the geometric location of the scanned hexagon image in invariant under any color mapping, and the relative location of the color contouring artifact within the hexagon can be identified via locating vertices and the center point of the scanned hexagon image. Because the colorant combination of the hexagon is known, we can accurately pinpoint the locations in the device color space where contouring artifacts appear in spite of the mapping error caused by $M_s(r, g, b)$.

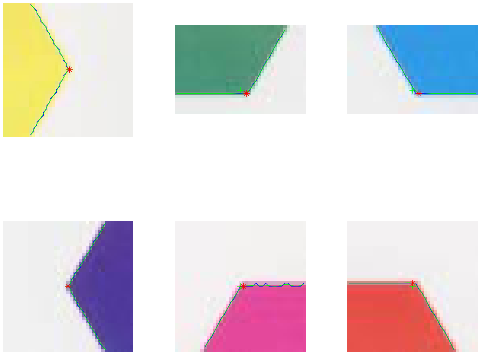

Figure 9: *Vertex Identification*

A progressive vertex searching algorithm is proposed. Assume that the background of the scanned image is primarily paper, and we can easily estimate the extent of two hexagon images horizontally and vertically. This, in turn, will offer enough geometrical information to approximately locate the positions of all vertices. In the refinement step, we assume that all pixels near an approximated vertex can be clustered into two groups in a color space; henceforth, boundary pixels can be located. Finally, recognizing that the curvature along the boundary reaches the maximum at the vertex, we can further refine the vertex location via fitting the boundary with a cubic spline curve and finding the maximal curvature point. Figure 9 demonstrates that this technique can pinpoint the vertex location accurately.

4. Contour Detection

Color contour can be characterized as the perceived color change within a small region exceeding a threshold. As a result, observers perceive color discontinuity at that location. That is, the color contouring artifact can be attributed to color gradient in the spatial domain. However, directly computing color gradient is problematic because the descreened image still contains noise from the printing process and differentiation is inherently a high-pass filter. Hence, the signal from the actual color contour will be covered by enhanced noise after simply computing color gradient. Consequently, it is necessary to preprocess the image to achieve two objectives: smoothing out the printing noise and preserving color contour. We can achieve these objectives by adopting the color sigma filter [7]. This filter first slides a small window across the image and only applies the filter at the pixels which are identified as being in the same cluster as the center pixel. As a result, the smoothing effect does not run across the contour; therefore, the filtered image becomes piecewise smooth and edges are preserved. Figure 10 and 11 shows a descreened top hexagon scanned from a print sample and its corresponding sigma-filtered image. The image profiles as shown in Figure 12 and 13 further demonstrate that the proposed color sigma filter is capable of achieving two objectives noted previously.

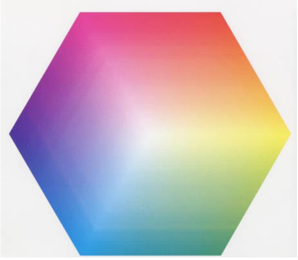

Figure 10: *Descreened Top Hexagon*

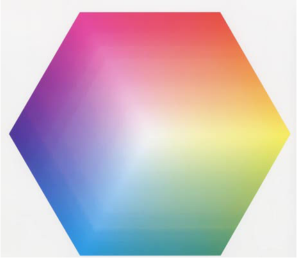

Figure 11: *Denoised Top Hexagon*

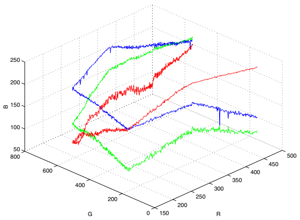

Figure 12: *Profile on the descreened image*

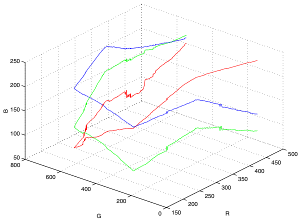

Figure 13: *Profile on the denoised image*

By mapping the sigma filtered *RGB* image into the *CIE Lab* color space based on the quadratic polynomial regression function, a device-independent and perceptually more unform analysis can be achieved. Assume M_f is the mapping function and $I_{sf}(R,G,B)$ is the sigma-filtered descreened image, and we can apply the gradient operator on the transformed image $\hat{I}_{sf}(L,a,b) = M_f(I_{sf}(R,G,B))$, where the *forward*, *backward* and *central difference* are adopted according to various boundary conditions. The vector norm is adopted to represent the magnitude of the color gradient, $|\nabla Color|$. After applying a Gaussian low pass filter to reduce the amount of erroneous peaks of color gradient, the location of the color contouring artifacts can be identified as the pixels with $|\nabla Color|$ exceed a predefined threshold.

5. Experiment Result

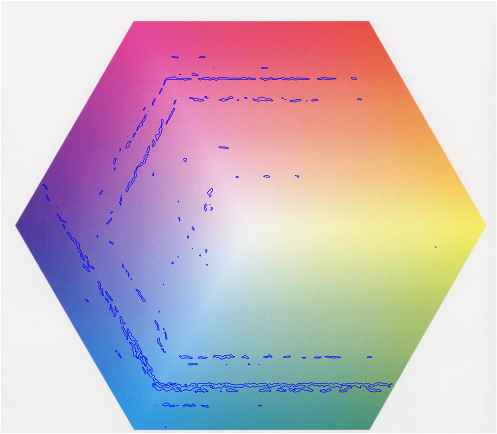

Figure 14: *The location of identified color contour*

Figure 14 shows the descreened image and the identified possible color contour pixels. They are very close to the perceived color contour locations although it also identifies some isolated spots as being color contour because of printing artifact. As a result, we demonstrates that the proposed algorithm is able to analyze the color contouring artifacts of a printing system in a device independent and perceptual-based manner.

6. Conclusion

We have proposed a color contouring analyzing technique combining scanner calibration, machine vision and image processing algorithms. The color mapping function obtained from scanner calibration allows us to analyze the image consistently in a more perceptually uniform space. The vertices identified by the proposed technique offers an accurate reference points to relate the positions of the color contour to the device color space. Finally, the color sigma filter is adopted to preprocess the descreened image to obtain the color gradient magnitude, which can be used to locate the possible color contouring artifact positions.

7. References

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8. Biography

Chunghui Kuo received his Ph.D in Electrical and Computer Engineering from University of Minnesota and joined *NexPress* since 2001. His research interest is in image processing, image quality and neural network applied in signal processing. He is a member of IEEE signal processing society and *IS&T*.

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