Journal of Imaging Science and Technology® 56(1): 010505-1–010505-7, 2012.

Assessment of Color Fringe on Scanned Images

Seul Ki Jang and Choon-Woo Kim▲
School of Information and Communication Engineering, Inha University, Yonghyeon 4-dong, Nam-gu, Incheon 402-751, Korea
E-mail: cwkim@inha.ac.kr

Abstract. *Scanner, as a component of multifunction peripheral or standalone device, is widely utilized for document scanning and copying. There are various image quality attributes affecting performance of scanners. This article is focused on quantitative evaluation of color fringe on scanned images. Based on results of interview with participants in human visual experiments, major attributes affecting perceived degrees of color fringe are selected first. Formulas for selected attributes are defined. Proposed evaluation model is constructed as a linear combination of selected attributes by applying linear regression to values of calculated attributes and just noticeable difference scores by human visual experiments. Experimental results indicate that the calculated measures from the proposed model faithfully match with results of human visual experiments.* © *2012 Society for Imaging Science and Technology.*
[DOI: 10.2352/J.ImagingSci.Technol.2012.56.1.010505]

INTRODUCTION

Digital copiers or multifunction peripherals have been widely utilized for document scanning, printing, and copying. Most of them contain flatbed scanner unit for digital image acquisition. Quality of scanned images is majorly determined by performance of an embedded scanning unit. Also, image quality of copying function is affected by performance of scanning and printing imaging chain. With increase in spatial resolution, flatbed scanner can be utilized as a measurement device. For example, feasibility of utilizing flatbed scanners as measuring devices for quality evaluation of printed images has been studied.[1–6] Flatbed scanner is cost-effective and faster than conventional drum scanner and microdensitometer. In order to employ flatbed scanner as a measuring device, its performance needs to be characterized and compensated.

Various techniques have been proposed to improve image quality of scanning and copying. However, works on quantitative analysis of the scanned image quality are scarce.[3–9] Comprehensive evaluation methods for scanner image quality attributes can be found in previous work.[3] Image quality attributes for scanners include tone scale, temporal and spatial uniformity, start-of-scan jitter, geometric distortion, signal-to-noise ratio, dynamic range, modulation transfer function, flare, and integrating cavity effect.[3] This article is focused on quantitative evaluation for color fringe that is not fully investigated in previous works.

▲IS&T Member.

Received Jul. 22, 2011; accepted for publication Nov. 17, 2011; published online Mar. 14, 2012.
1062-3701/2012/56(1)/010505/7/$20.00.

Color fringe is defined as undesirable color artifacts appearing on the edges of objects. It is mainly due to sensor misalignment, nonuniformity of scanner carriage motion, and optical aberration.[9] Previous works on the characterization of color fringe are rare. As a related work, the measurement of color fringe on the image captured by digital camera is proposed.[10] Two types of color fringe are defined: blue and red fringes. In order to measure perceived color fringe, two attributes, "size of fringe" and "intensity of fringe," are proposed.[10] They are measured across the black-and-white transition on the images specified by ISO 12233.[11] Size of fringe is defined as the number of pixels, whose normalized gray level difference between blue/red and green channels exceeds the predetermined threshold. Intensity of fringe was defined as the average value of the normalized differences. However, the relationship between these measures and the perceived degree of color fringe is not reported.[10]

Objective of this article is to propose a quantitative evaluation model for color fringe on scanned images. Preliminary human visual experiments are performed to identify major attributes affecting perceived degrees of color fringe. Based on interview with participants in human visual experiments, four different attributes are selected. Formulas for the selected attributes are defined. Proposed evaluation model is constructed as a linear combination of the attributes by applying linear regression to values of the calculated attributes and the just noticeable difference (*JND*) scores obtained by human visual experiments. Performance of the proposed model is verified using testing images that are not utilized for the model construction. Experimental results indicate that the calculated measures by the proposed model faithfully match with results of human visual experiments.

In "Attributes for Color Fringe Evaluation" section, the selected attributes to describe perceived degrees of color fringe and their formulation are explained. In "Color Fringe Evaluation Model" section, construction of the proposed evaluation model is presented. In next section, "Experimental Results" are discussed. Finally, conclusion is addressed in "Conclusion" section.

ATTRIBUTES FOR COLOR FRINGE EVALUATION

Identification of Key Attributes

Test pattern utilized in this study consists of equally spaced solid black rectangles on white background as shown in Figure 1. It is a portion of a test chart specially designed for image quality evaluation of scanners. The test chart was made by off-set printing. Figure 2 shows examples of scanned images. Size of scanned images is quadrupled for ease of comparison. Figs. 2(a) and 2(b) represent examples with and without color fringe, respectively. In Fig. 2(c), black rectangles of the test pattern exhibit chromatic colors. However, they may be due to inadequate gray balancing and/or color correction procedures. Thus, the image in Fig. 2(c) is not regarded as a sample with color fringe. Figure 3 illustrates variations of the lightness and chroma along vertical direction of the images in Fig. 2. In Fig. 3(a), peaks of chroma represent color fringe and they are located at the borders of the black rectangles. However, peaks of chroma are located in the middle of the black rectangles in Fig. 3(c).

Preliminary human visual experiments are performed to identify major attributes affecting perceived color fringe. Participants are asked to choose the image with greater visibility of color fringe in a paired comparison and provide reasons for their choices. In addition to size of fringe and intensity of fringe proposed in previous work,[10] "relative lightness of background" and "variety in hue" are identified based on interview with the participants. As contrast between black rectangle and background increases, visibility of color fringe is decreased. However, diversity of hue enhances visibility of color fringe. Also, higher values of chroma and wider width of color fringe increase the visibility.

Color Fringe Extraction

In order to quantify four attributes, a scanned image is segmented into three subareas; color fringe, object, and background. Figure 4 shows flow chart of the color fringe extraction method utilized in this article. The standard sRGB to $L^*a^*b^*$ coordinates transformation matrix specified in IEC61966-2-1[12] is utilized to convert scanner RGB coordinates to $L^*a^*b^*$. For each of horizontal lines, the average values of L^*, a^*, and b^* are calculated. A thresholding method based on the discriminant analysis technique[13] is applied to the averaged values of L^* to extract the areas of objects. Lines containing color fringe are extracted when they obey the following three conditions: First, the lines of color fringe should be located on the boundary of the black rectangles. Thus, the averaged L^* of the lines of color fringe should be greater than the averaged L^* of objects and smaller than the averaged L^* of the background. They are denoted as L^*_{obj}, L^*_{back}, and L^*_i in Fig. 4. Second, the averaged value of chroma C^*_i should be greater than a predetermined threshold T_c. Third, the color difference in CIE $L^*a^*b^*$ space (ΔE) between the lines of color fringe and those of objects should be greater than a predetermined threshold T_e. It should be mentioned that the extraction of color fringe is made based on the aforementioned conditions, whereas a simple thresholding in RGB space was employed.[10] Procedure to determine the values of thresholds, T_c and T_e, will be explained later.

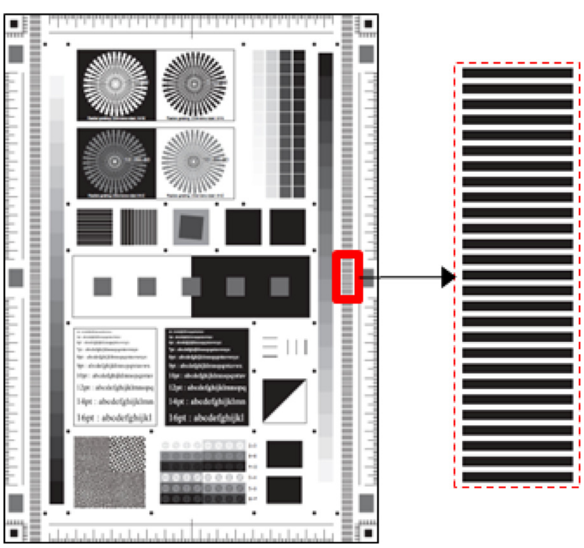


Figure 1. Test pattern.

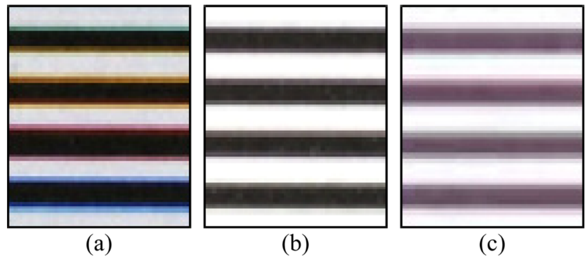


Figure 2. Examples of color fringe on scanned images: (a) image with color fringe, (b) image without color fringe, (c) image with poor gray balance.

Formulation of Key Attributes

Calculation of the selected attributes is explained next. All the attributes are defined such that their values range from 0 to 1. Higher value of the attributes implies higher visibility of color fringe. In previous method,[10] intensity of fringe was calculated using the normalized difference in RGB coordinates. However, in this article, it is defined based on the averaged value of chroma as

$$f_I = \frac{m_{\text{chroma}}}{m_{\text{chroma,max}}}, \tag{1}$$

where m_{chroma} represents the averaged value of chroma for the lines of color fringe on a given image. $m_{\text{chroma,max}}$ denotes the maximum value of chroma among all the scanned images tested.

Similarly, relative lightness of background is defined as

$$f_R = \frac{m_{L^*,\text{object}}}{m_{L^*,\text{back}}}, \tag{2}$$

where $m_{L^*,\text{back}}$ and $m_{L^*,\text{object}}$ represent the averaged L^* of the lines of background and object, respectively. It is defined as reciprocal of the contrast between the objects and background because the visibility of color fringe

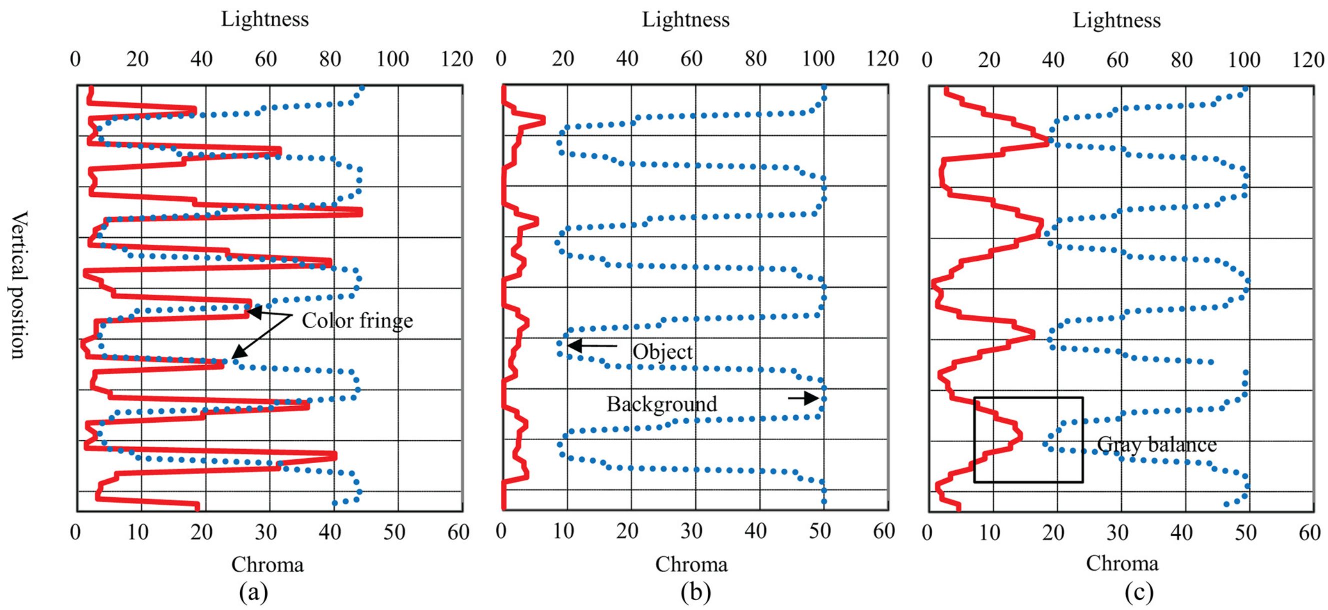


Figure 3. Lightness and Chroma for vertical lines: (a) image with color fringe, (b) image without color fringe, (c) image with poor gray balance.

decreases as the contrast increases. Variety in hue is to measure diversity of hues. First, a^*–b^* plane is divided into two sections having 180° of hue angles. Ratio of distinct hue sections where the lines of color fringe belong to is counted. This procedure is repeated for 4, 6, 9, 18, 36, and 72 sections. Variety in hue is defined as the average of seven calculated ratios as

$$f_H = \frac{(h_2 + h_4 + h_6 + h_9 + h_{18} + h_{36} + h_{72})}{7}, \tag{3}$$

where h_n denotes the ratio of distinct hue sections when a^*–b^* plane is divided into n subsections. Size of fringe is to measure width of color fringe and calculated by

$$f_S = \frac{n_{\text{line}}}{n_{\text{line,max}}}, \tag{4}$$

where n_{line} represents the number of the lines extracted as the color fringe from a given image. $n_{\text{line,max}}$ denotes the maximum number of the lines representing the color fringe among all the scanned images tested.

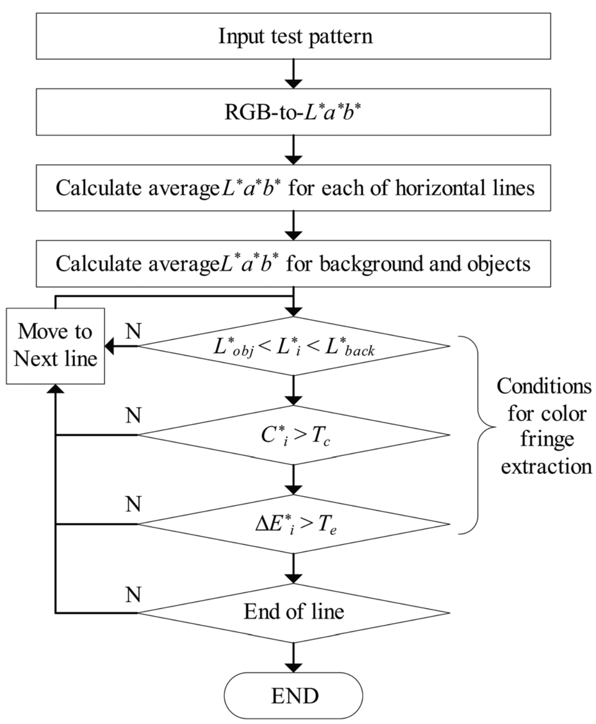


Figure 4. Flow chart of the color fringe extraction method.

COLOR FRINGE EVAUATION MODEL

Figure 5 illustrates flowchart to determine the proposed color fringe evaluation model. In order to design color fringe evaluation model that faithfully matches with results of human visual experiments, four attributes are selected based on characteristics of perceived color fringe. Objective values of the selected attributes are calculated from each of training images. Human visual experiments are performed to obtain subjective scores. The color fringe evaluation model is constructed by applying linear regression technique to the subjective scores of human visual experiments and the objectives value of the selected attributes. Conditions for human visual experiment and selection of training images are described next. Also, construction of the proposed evaluation model for color fringe is explained.

Conditions for Human Visual Experiments

In a dark room, human visual experiments are carried out on a standard sRGB LCD monitor. Paired comparison is employed, because the one-to-one comparison makes it

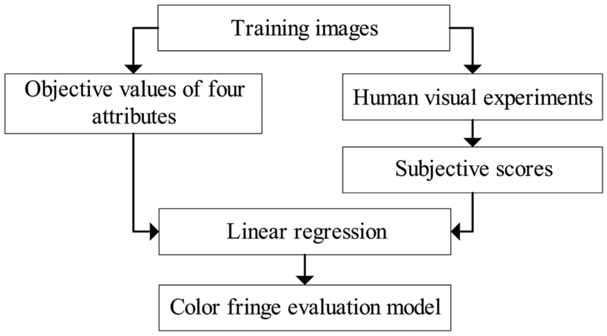


Figure 5. Flow chart to construct the color fringe evaluation model.

easier to discriminate differences in visibility of color fringe.[14,15] Twelve observers are participated and asked to choose the image giving an impression of higher color fringe. If unable to distinguish, they are allowed to say that two images are in the same degree of perceived color fringe. The preferred image obtains a score of 1 and the other one gets a score of 0. When judged as the same level, both of images will get a score of 0.5.

Subjective scores of the human visual experiments are calculated by the Thurston's law of comparative judgments.[16] Equation (5) is utilized for conversion from the outcomes of the paired comparisons to the *JND* values.[17]

$$JND = \frac{12}{\pi}\sin^{-1}(\sqrt{p}) - 3, \tag{5}$$

where p is a probability of preference in paired comparisons. Suppose that scanned image "A" is compared with scanned image "B" by ten observers. When seven observers give a score of 1 to image A, one observer gives a score of 0.5 and two observes give a score of 0, p for the image A becomes $7.5/10 = 0.75$.

Selection Method for Training Images

Test pattern is scanned by 40 different scanners that cover low-end to high-end scanners available in market. Scanning is made under factory default conditions, and scanning resolution is 300 dpi. Selection of training images should be carefully made to extract reliable results from human visual experiments. Selection procedure is explained by an example in Table I. Suppose that (1) to (10) in Table I represent ten scanned images arranged in ascending order of the visibility of color fringe. The number in the (i + 1)th row and the (j + 2)th column represents the *JND* difference between images (i) and (i + 1). When the *JND* between images (i) and (i + 1) is too small, participants would not be able to discriminate. In this article, training images are selected such that the *JND* between image (i) and (i + 1) should be around the *JND* scale of 1. The *JND* scale of 1 implies that one image is preferred with a probability of 0.75. In Table I, image (1) is selected because it is the first image. Image (2) is also selected because the *JND* difference between images (1) and (2) is 1. But image (3) is not chosen because the *JND* difference between images (2) and (3) is 0.48. Because

Table I. Examples of human visual test results.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	0	**1**	1	1.19	1.39	1.88	2.21	3	3	3
(2)	−1	0	0.48	**0.95**	1.62	3	1.39	2.21	3	3
(3)	−1	−0.48	0	1.39	1.19	1.62	2.21	1.88	3	3
(4)	−1.19	−0.95	−1.39	0	**1.39**	1	1.88	1.88	3	3
(5)	−1.39	−1.62	−1.19	−1.39	0	0.38	**1**	1.62	3	3
(6)	−1.88	−3	−1.62	−1	−0.38	0	0.65	1.62	2.21	3
(7)	−2.21	−1.39	−2.21	−1.88	−1	−0.65	0	**1.39**	1.62	3
(8)	−3	−2.21	−1.88	−1.88	−1.62	−1.62	−1.39	0	**0.95**	3
(9)	−3	−3	−3	−3	−3	−2.21	−1.62	−0.95	0	**1.39**
(10)	−3	−3	−3	−3	−3	−3	−3	−3	−1.39	0

image (3) is not chosen, the *JND* difference between images (2) and (4) is examined whether to select image (4). In this example, image (4) is selected because the *JND* difference between images (2) and (4) is 0.95. This procedure is repeated to select the training images for visual experiments. **Bold** numbers in the first row represent the selected images in this example.

In this article, among 40 scanned images, 12 images satisfying the aforementioned *JND* conditions are selected. The results of human visual experiments with 12 training images are utilized for construction of the proposed evaluation model.

Construction of Evaluation Model

Evaluation model for color fringe is designed as a linear combination of four attributes. For each of training images, values of four attributes are calculated. Coefficients of linear combination are estimated by applying linear regression to the subjective scores from visual experiments and the calculated values of the attributes. Equation (6) defines the proposed model for color fringe.

$$Q_{\text{color fringe}} = (5.74) \times f_I + (4.90) \times f_S + (3.43) \times f_H + (1.90) \times f_R \tag{6}$$

In Eq. (6), the attribute f_I, intensity of fringe, has the largest weight. f_S, size of fringe, has the second largest weight. This implies that intensity of fringe and size of fringe play as key factors determining the visibility of color fringe.

In order to identify statistical significance for the selected attributes, we examined p-values from Minitab[18] utilized for linear regression. For a linear regression, it is desirable to have p-values less than the significance level 0.05.[19] In this study, all the p-values for the selected attributes are less than 0.05. Value of the correlation coefficients between the calculated metrics $Q_{\text{color fringe}}$ in Eq. (6) and the subjective scores for 12 training images is 0.90.

EXPERIMENTAL RESULTS

Construction of color fringe evaluation models has been described. In this section, validity of the proposed model is examined. Also, performance of the proposed model is compared with that from previous work.[10] Effects of the selected attributes are explained by examples. Performance of color fringe extraction is analyzed.

Experimental Results with Testing Images

In order to evaluate performance of the proposed model, separate human visual experiments are performed using testing images. Conditions of the visual experiments are the same as in the model construction. In this article, we collected sample images from 40 different scanners. Among 40 scanned images, 12 images representing full dynamic ranges of the perceived color fringe are utilized as the training samples for model generation. The remaining 28 images representing 28 different scanners are employed as testing samples for performance evaluation. Calculated values of Eq. (6) are obtained from each of the testing images. Correlation coefficient between the calculated metrics and subjective scores for the testing images is 0.89. It is very close to the value of the correlation coefficient for training images, 0.90.

Comparison with Previous Work

Two attributes, size of color fringe and intensity of color fringe, were proposed to represent visibility of color fringe on the photographs taken by digital camera.[10] Two attributes were calculated based on RGB coordinates. Relationship between these measures and the perceived degree of color fringe was not reported.[10] For fair comparison, the same training images are utilized for the model construction with two attributes proposed in previous work.[10] Equation (7) specifies the model.

$$P_{\text{color fringe}} = (18.58) \times I_{\text{blue fringe}} + (16.45) \times I_{\text{red fringe}} + (0.73) \times S_{\text{fringe}}. \quad (7)$$

In Eq. (7), $I_{\text{blue fringe}}$ and $I_{\text{red fringe}}$ denote the intensity of blue and red fringe, respectively. S_{fringe} denotes the averaged size of color fringe. Values of correlation coefficients for the training and testing images are 0.81 and 0.80, respectively.

Figures 6(a) and 6(b) illustrate the relationship between the quantified metrics and subjective scores. Horizontal axis represents perceived image quality in the *JND* scale calculated from the results of the human visual experiments. Vertical axis denotes the quantified metrics by the evaluation model. It can be seen from the values of correlation coefficients and Fig. 6 that the proposed evaluation model yields better performance than previous method.[10]

Effects of Selected Attributes

Justification of four attributes utilized in this article can be explained by an example in Figure 7. From the visual experiments, degree of the perceived color fringe for "image 2" in Fig. 7 is higher than "image 1." However, the values of f_I, f_S, and f_R are in reverse order. Only the value of f_H agrees with the results from the human visual experiments. The proposed model yields the same order as in the human visual experiments. The calculated measure based on previous work[10] does not agree with the results from the human visual experiments. It can be said that f_H plays as a key factor affecting the visual perception of color fringe in this case.

Figure 8 illustrates another example. In this case, degree of the perceived color fringe for "image 4" in Fig. 8 is higher than "image 3." The values of two attributes, f_I and f_S, are in reverse order. But the values of two remaining attributes, f_H and f_R, match with the visual perception. The calculated measure from the proposed model is in concordance with the results from the visual experiments.

Figure 9 illustrates the last example. In this case, the values of three attributes f_I, f_S, and f_H are in reverse order.

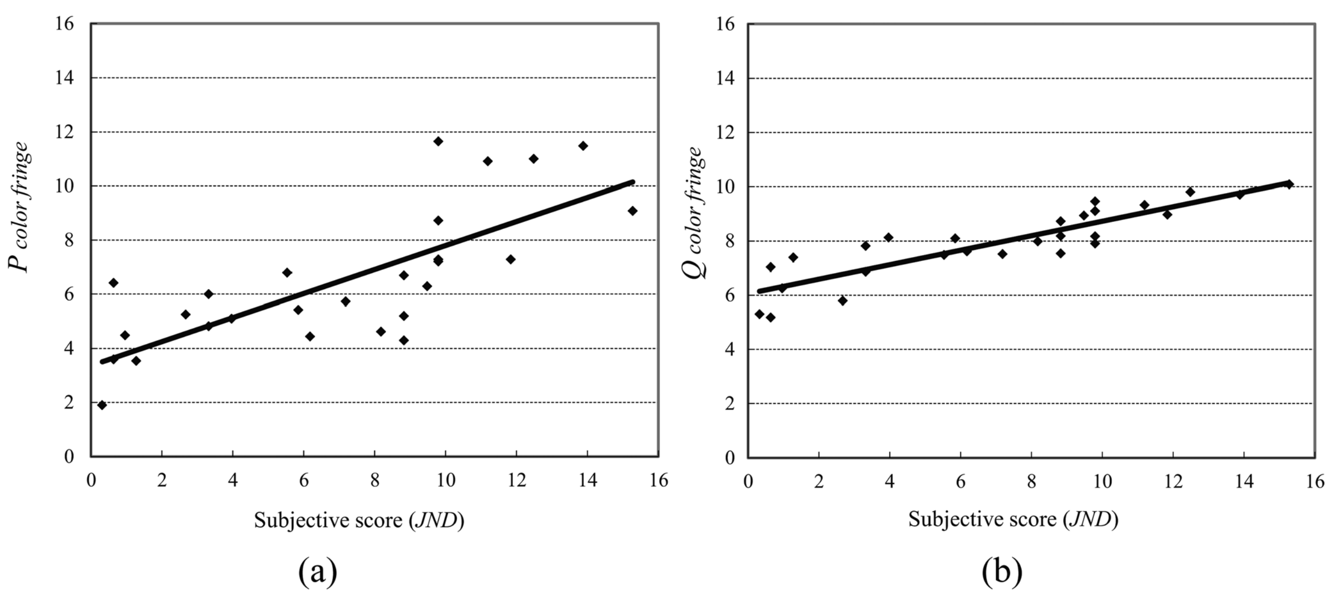
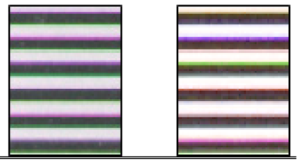
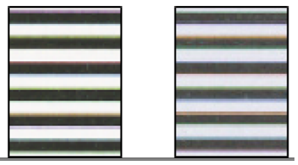


Figure 6. Correlations between the subjective score and quantitative scores: (a) Previous method (b) Proposed method.



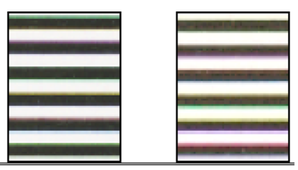
Perceived level(JND)	9.79	<	13.88
f_I	0.79	>	0.68
f_S	0.55	>	0.53
f_H	0.33	<	0.72
f_R	0.43	>	0.25
Measure from previous work (Eq. (7))	10.94	>	8.55
Proposed measure (Eq. (6))	9.18	<	9.44
	(a)		(b)

Figure 7. An example for performance evaluation (case1).



Perceived level(JND)	7.18	<	8.18
f_I	0.22	>	0.18
f_S	0.52	>	0.50
f_H	0.68	<	0.81
f_R	0.27	<	0.40
Measure from previous work (Eq. (7))	5.73	>	4.61
Proposed measure (Eq. (6))	6.65	<	7.02
	(a)		(b)

Figure 8. An example for performance evaluation (case2).



Perceived level(JND)	8.83	<	9.47
f_I	0.37	>	0.34
f_S	0.62	>	0.61
f_H	0.75	>	0.74
f_R	0.07	<	0.37
Measure from previous work (Eq. (7))	6.68	>	5.19
Proposed measure (Eq. (6))	7.87	<	8.18
	(a)		(b)

Figure 9. An example for performance evaluation (case3).

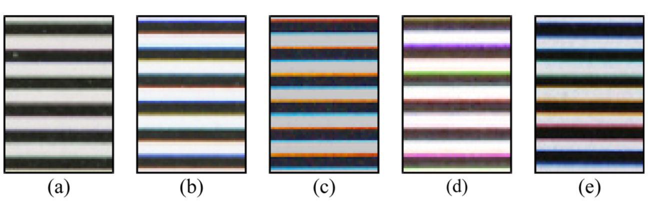


Figure 10. Scanned images for ground truth data.

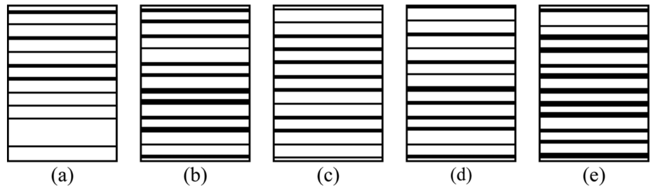


Figure 11. Ground truth data manually extracted from the images in Fig. 10.

Only f_R agrees with the result from the human visual experiments. Again, the proposed yields the same order as in the human visual experiments. These examples may justify the need for utilizing four attributes in the model construction.

Performance of Color Fringe Extraction

Another factor affecting the performance of the proposed model is accuracy of color fringe extraction from the scanned images. In order to determine two thresholds, T_c and T_e in Fig. 4, lines containing color fringe are manually extracted from scanned images. Figures 10 and 11 illustrate some of the scanned images and the results of manual extraction, respectively. The images in Fig. 11 are utilized as ground truth data to determine values of T_c and T_e. Also, a measure of extraction accuracy is defined. Percentage of color fringe lines that are correctly classified as color fringe is called as a true positive (TP). Percentage of noncolor fringe lines that are correctly classified as noncolor fringe is called as false negative (FN). An average of the TP and FN serves as a measure of the extraction accuracy. Ideally, value of the measure should be 1. The extraction accuracies are calculated for different values of T_c and T_e. Values of T_c and T_e yielding the maximum extraction accuracy are selected. Values of T_c and T_e utilized in this study are 3 and 2, respectively.

Figure 12 illustrates the results of extraction by the proposed thresholding method and the previous method.[10] Calculated values of the TP, FN, and the proposed extraction accuracies are shown in Figure 13. It can be noticed from Figs. 12 and 13 that the proposed method outperforms the previous method.[10] Also, robustness against the thresholds, T_c and T_e, can be verified by Figure 14 that illustrates plot of the extraction accuracies for different values of T_c and T_e. The extraction accuracies are quite flat near

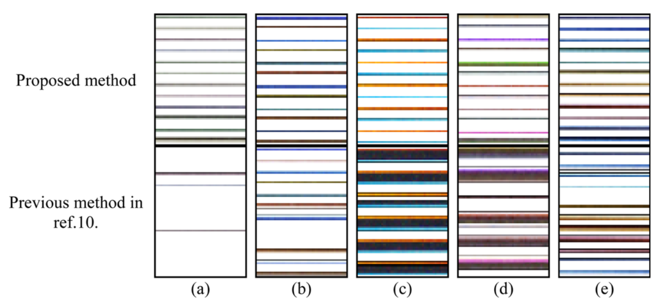


Figure 12. Results of color fringe extraction for the images in Fig. 10.

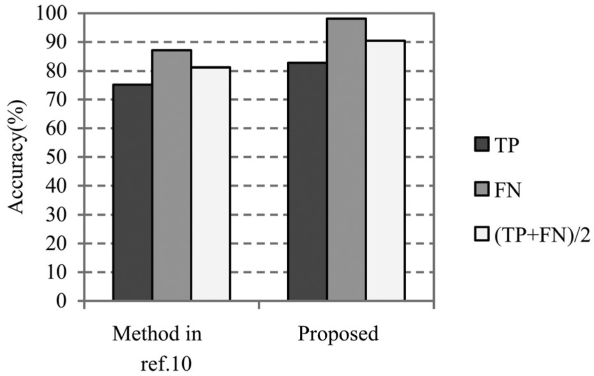


Figure 13. Comparison of extraction accuracies.

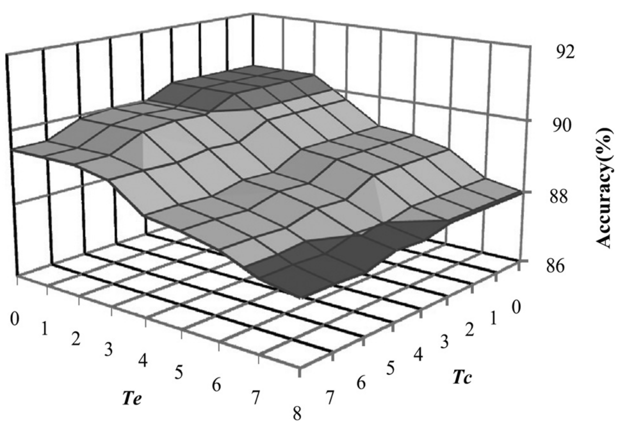


Figure 14. Color fringe extraction accuracies for different thresholds T_c and T_e.

the selected values of T_c and T_e. The maximum and minimum accuracies for the ranges of T_c and T_e in Fig. 14 are 90% and 88%, respectively.

CONCLUSION

In this article, a quantitative evaluation model for color fringe on scanned images is proposed. Four attributes affecting the perceived degree of color fringe are identified based on interview with participants in visual experiments. Formulas for the selected attributes are defined on CIE $L^*a^*b^*$ space. They are calculated to be in the range from 0 to 1. The proposed evaluation model is constructed by applying linear regression to the values of attributes and the *JND* score by the visual experiments. Experimental results indicate that the results of the proposed evaluation method faithfully match with the results from the human visual experiments. The methodology to construct an evaluation model for color fringe can be utilized for other image quality attributes for scanners. The proposed model can serve as a tool to measure visibility of color fringe. However, impact of color fringe on perceived image quality of scanned images can be investigated in future.

ACKNOWLEDGMENTS

This work was supported by the research grant from Samsung Electronics (2009-38184).

REFERENCES

[1] D. R. Rasmussen, B. Mishra, and M. Mongeon, "Using drum and flatbed scanners for color image quality measurements", *Proc. IS&T's PICS 2000: Image Processing, Image Quality, Image Capture, Systems Conference* (IS&T, Springfield, VA, 2000), pp. 108–113.

[2] H. Shin, E. N. Dalal, and D. R. Rasmussen, "Predicting customer preference from objective image quality metrics for monochrome document products", Proc. SPIE **5294**, 155–164 (2004).

[3] E. K. Zeise, "Characteristic measurements for the qualification of reflection scanners in the evaluation of image quality attributes", Proc. SPIE **7242**, 724202 (2009).

[4] E. K. Zeise, W. C. Kress, and D. R. Williams, "Characterization of reflection scanner uniformity", Proc. SPIE **6808**, 680803 (2008).

[5] C. Kuo, D. Lai, and E. K. Zeise, "Scanner-based macroscopic color variation estimation", Proc. SPIE **6059**, 60590G (2006).

[6] D. Hertel, "Exploring s-CIELAB as a scanner metric for print uniformity", Proc. SPIE **5668**, 51–60 (2005).

[7] C. Cui, "Scanner motion error detection and correction", Proc. SPIE **6494**, 64940R (2007).

[8] P. D. Burns, "Tone-transfer (OECF) characteristics and spatial frequency response measurements for digital cameras and scanners", Proc. SPIE **5668**, 123–128 (2005).

[9] R. G. Gann, *Desktop Scanners: Image Quality Evaluation* (Prentice Hall, NJ, 1998).

[10] F. Cao, F. Guichard, H. Hornung, and C. Sibade, "Characterization and measurements of color fringing", Proc. SPIE **6817**, 68170G1(2008).

[11] ISO 12233: 2000, *Photography—Electronic Still Picture Cameras—Resolution Measurements* (ISO, Geneva, 2000), www.Iso.org.

[12] IEC 61966-2-1, *Multimedia Systems and Equipment—Colour Measurement and Management—Part 2-1: Colour Management—Default RGB Colour Space—sRGB* (ISO, Geneva, 1999), www.iso.org.

[13] N. Otsu, "A threshold selection method from gray-level histogram", IEEE Trans. Syst. Man Cybern. **1**, 62–66 (1979).

[14] G. A. Gescheider, *Psychophysics: Method, Theory, and Application* (Psychology, NJ, 1984).

[15] P. G. Engeldrum, *Psychometric Scaling: A Toolkit for Image Systems Development* (Imcotek, MA, 2000).

[16] L. L. Thurstone, "A law of comparative judgment", Psychol. Rev. **34**, 273–286 (1927).

[17] B. W. Keelan, *Handbook of Image Quality: Characterization and Prediction* (CRC, NY, 2002).

[18] B. F. Ryan, *Minitab Handbook* (Thomson Learning, CA, 2004).

[19] D. C. Montgomery and G. C. Runger, *Applied Statistics and Probability for Engineers* (John Wiley & Sons, Inc., NJ, 2002).