https://doi.org/10.2352/ISSN.2470-1173.2017.12.IQSP-236
© 2017, Society for Imaging Science and Technology

Solid-Mottle Method for Measuring in Laser-Printers

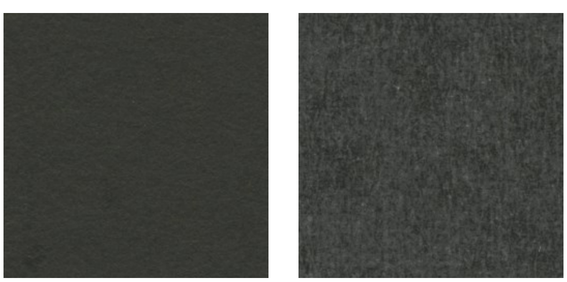
Dae-Gun Ko, Su-Han Song, Ki-Youn Lee, You-Sun Bang, Ki-Min Kang and Seong-Wook Han
Samsung S-Printing Solution, 130, Samsung-ro, Yeongtong-gu, Suwon-si, Gyeonggi-do, Republic of Korea
{ dg.ko, suhan.song, dearky.lee, yousun.bang, kimin.kang, seongwook.han } @ samsung.com

Abstract

The Mottle analysis method is widely used to describe ISO 13660 and improved by ISO 24790. However, this method showed not enough satisfied correlation for ours. In this paper, we propose a new method for measuring effective noise analysis in solid area. We will name it as 'Solid-Mottle'. It is phenomenon of printing optical-density non-uniformity at solid-black, and it is occurred on laser-printers. The purpose of present paper is to offer an analysis of Solid-Mottle defect, test pattern and method for measuring. Quantified Solid-Mottle is measured based on psychophysical experiment. Parameter A and JND_{mottle} *is determined by human experiment. By conducting five-fold cross-validation, the strong correlation was obtained between the proposed method and perceived scales: the correlation coefficient r is 0.94, RMSE (Root Mean Square Error) is 0.34, respectively. In addition, the* F_1*-measure score is 0.92 by SVM (Support Vector Machine) approach.*

1. Introduction

Print image quality is an important factor for printer and MFP (Multi-Function-Printer) customers. For the reason, digital printing image quality automatically assessment has been widely used in scanning apparatus, such as scanner, CCD-Camera [4]. The definition and method for measuring of print image quality that has banding [5, 12], macro-uniformity [6, 7, 8], ghosting [9], gloss-mottle [4] and edge-effect [3] is introduced by ISO 13660 [1] and improved by ISO 24790 [2]. Solid image quality is one of fundamental attributes as density, darkness, void and consistency coverages.



(a) (b)

Figure 1. *Scanned Solid-Mottle samples are shown: (a) excellent (b) poor*

Solid-Mottle is printer's artifact which is phenomenon of printing optical-density non-uniformity at solid area [Fig 1]. The notion of mottle and graininess had described in the paper by K. Y. Lee *et al.* [11]. In the paper, quantified 2D noise metric was proposed and it has obtained large correlation coefficients between proposed metric and psychometric scales: *r* is 0.88 at black, *r* is 0.95 at magenta and *r* is 0.93 at cyan, respectively. Therefore, we conducted to verify method for 2D noise at solid-black. However, 2D noise metric is not well matched to perceived subjective result as shown in Fig. 2. In our aspect, the correlation coefficient is too low between 2D noise score and subjective score. Since the 2D noise metric cannot be to assess at solid area. In addition, according to the Mottle of ISO 24790 [2] working conducted by to compare Mottle methods. In the work, the best correlation coefficient of mottle was 0.626 by Lexmark method.

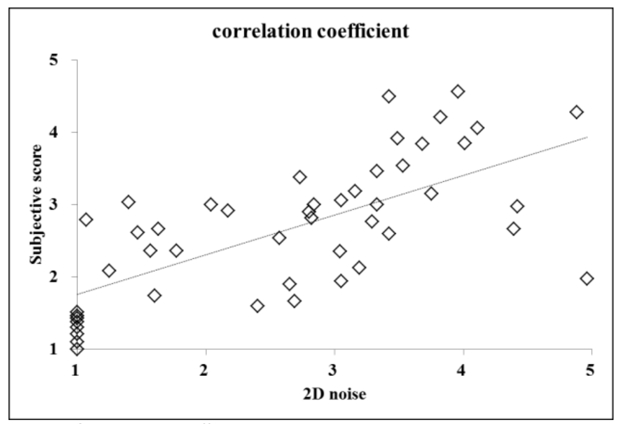


Figure 2. *Correlation coefficient between 2D noise score and subjective score: r is 0.71*

The goal of our approaches is to develop a quantified metric that can automatically assess solid image quality based on psychophysical experiment. In this paper, we designed test pattern and will propose quantified metric for solid-uniformity. We named it as Solid-Mottle in this method for measuring.

In recent years, W. Wang *et al.* [14] and M. Q. Nguyen *et al.* [10] had proposed print image assessment using SVM (Support Vector Machine) [15]. In the work, they proposed quantified uniformity metric using SVM and provided the efficacy of their method. Thus, we additionally conducted SVM modeling and verification.

The rest of the paper is organized as follows. In the next section, we provide both Solid-Mottle's test pattern and proposed method. In section 3, we will show large correlation coefficient and F_1*-measure* score between the proposed method and psychophysical experiment using five-fold cross-validation. We also talk about how to classify pass or fail in the section. In section 4, we derive a conclusion for Solid-Mottle and future work.

2. Proposed Method

Our approach is summarized by flow chart as shown in Fig. 3. The procedure for Solid-Mottle's Process A is as follows.

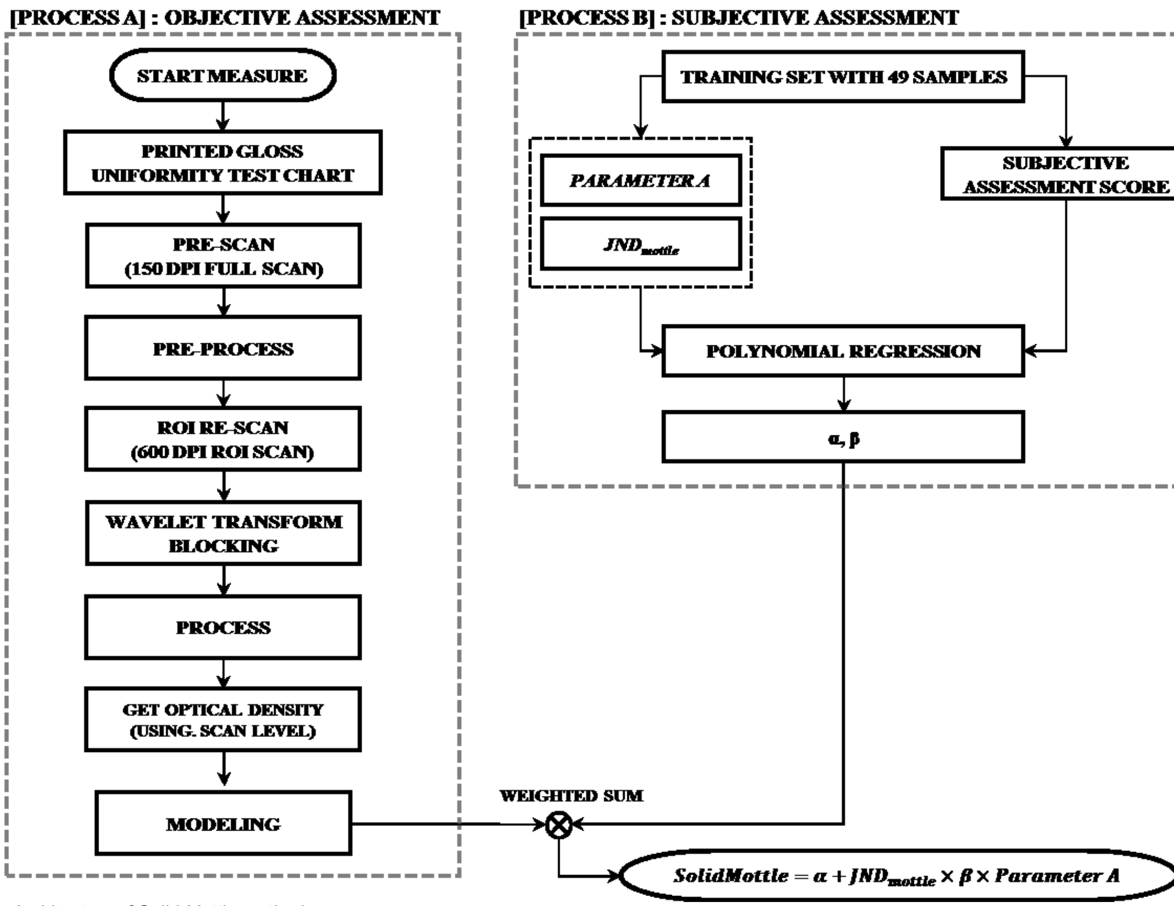


Figure 3. *Architecture of Solid-Mottle method*

The procedure for Process A	
1.	Printing test chart
2.	Chart pre-scanning at 150 dpi
3.	Chart recognition and scan area searching
4.	A test chart re-scanning at 600 dpi
5.	Wavelet transform: 4 level, bi-orthogonal 97
6.	Computing lightness and *Parameter A*
7.	JND_{mottle} modeling
8.	Solid-Mottle scoring

The Solid-Mottle score is obtained through weighted sum of *Parameter A* and JND_{mottle}.

2.1 Test chart design

For Solid-Mottle measuring, we used a test chart as in shown Fig. 4. This pattern is composed of graphic-black (R: 0, G: 0, B: 0) and image-black (rasterized R: 0, G: 0, B: 0) with various colors. Each sized of patch is 185 mm by 22 mm, and this pattern had made by graphics tool of Adobe Illustrator CS 6.

Figure 4. *Test chart for Solid-Mottle*

2.2 Subjective Assessment

For psychophysical experiment, we ready to have different levels of Solid-Mottle, we choose 49 test samples among nine print manufacturing, and two reference samples are selected: one has minimal defect, and the other has the worst level of defect.

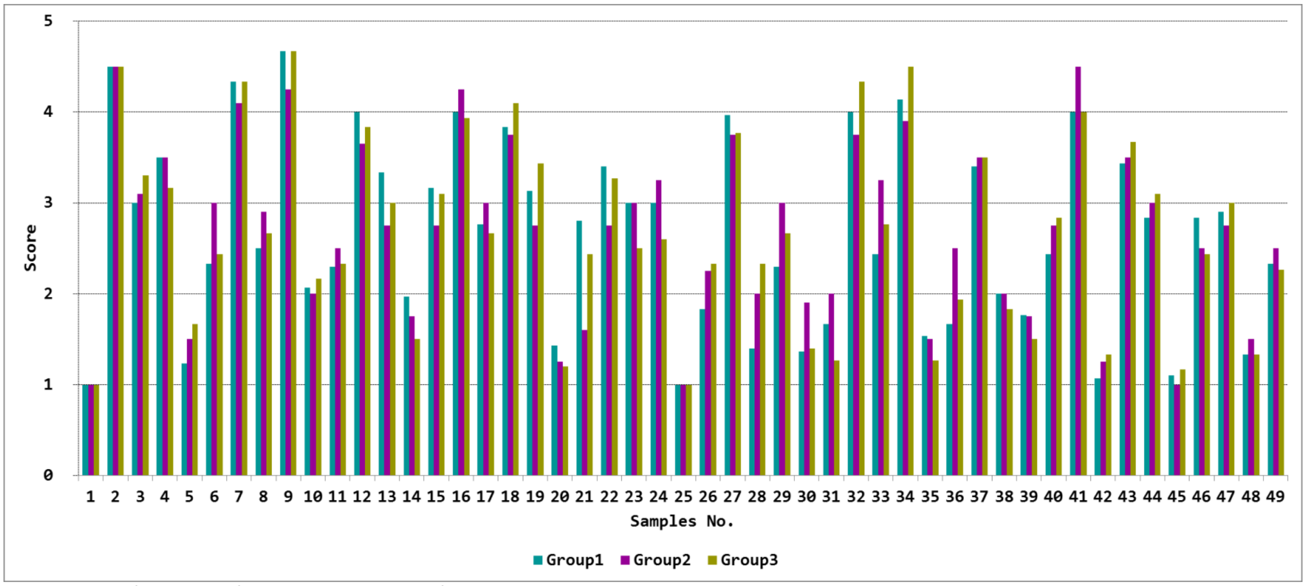
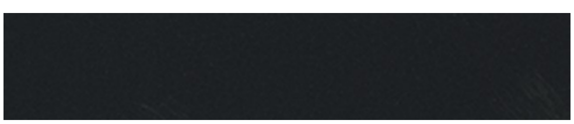


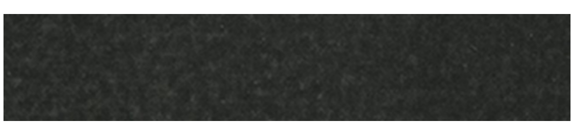
Figure 6. *Plot of the result of subjective assessment from 49 samples*

The best sample is assigned as Grade 1.0, and the worst sample is Grade 4.5 [Fig. 5]. Observers can mask Grade 1.0 to Grade 5.0 with respect to the degree of defect.

The subjective assessment was conducted in an office under the normal lighting condition environments. We sufficiently explain to observers the definition of Solid-Mottle using two reference samples. From the psychophysical experiment, we excluded 1 outlier among 15 observers (the correlation coefficient between outlier and average was 0.76), and get a minimum correlation coefficient *r* was 0.88 between a single observer and the average score. The result of the subjective assessment is shown in Fig. 6. As in Fig. 6, the Solid-Mottle visually scores for Group 1 to Group 3 are mostly to get similar scores (Group 1 consists of print image quality experts, Group 2 are printer developers and Group 3 are ordinary person who are unfamiliar with print image quality. The represented scores are average values by each group). However, an outlier whose slightly misunderstand a meaning as for Solid-Mottle definition took a different result.



(a)



(b)

Figure 5. *Solid-Mottle defects scanned:*
(a) has minimal defect as 1.0 score, (b) has worst defect as 4.5

2.3 Parameter A

Firstly, a test pattern is scanned by scanner device, we used the Epson Expression 10000XL. To compute *Parameter A*, we selected five ROI (Region Of Interest) with the sized of 10.9 mm by 10.9 mm each patch, and cropped ROI divided into 64 (8 x 8) non-overlapping square tiles as depicted on Fig 8.

Secondly, scanned RGB values are converted lightness values as the *Eq. 1* and computing average lightness value. In addition, high frequency noise, band and streak are removed using wavelet transform [13]. We used Daubechies wavelet of order 97 and the number of wavelet levels *n* is 4, and we conducted zero padding about all the details components (vertical, horizontal and diagonal) of the three levels [Fig. 7]. Finally, to get a filtered image, we get an inverse wavelet image and compute *Parameter A* [*Eq. 2*] as standard deviation of average with in respective cropped ROI.

(a) (b)

Figure 7. *An example of wavelet transform image:*
(a) original image (b) wavelet filtered image

$$lightness = 0.3 \times R + 0.5 \times G + 0.2 \times B \tag{1}$$

$$Parameter\ A = \sqrt{\frac{\sum_{i=1}^{64}\left(\frac{\sum_{i=1}^{64} v_i}{64} - v_i\right)^2}{64}} \tag{2}$$

$where, v_i\ is\ average\ of\ lightness\ in\ corresponding\ each\ tiles$

Moreover, JND_{mottle} is represented by *Parameter A* with printing OD (Optical Density same as scanned lightness value). It is described next sub-sections in detail.

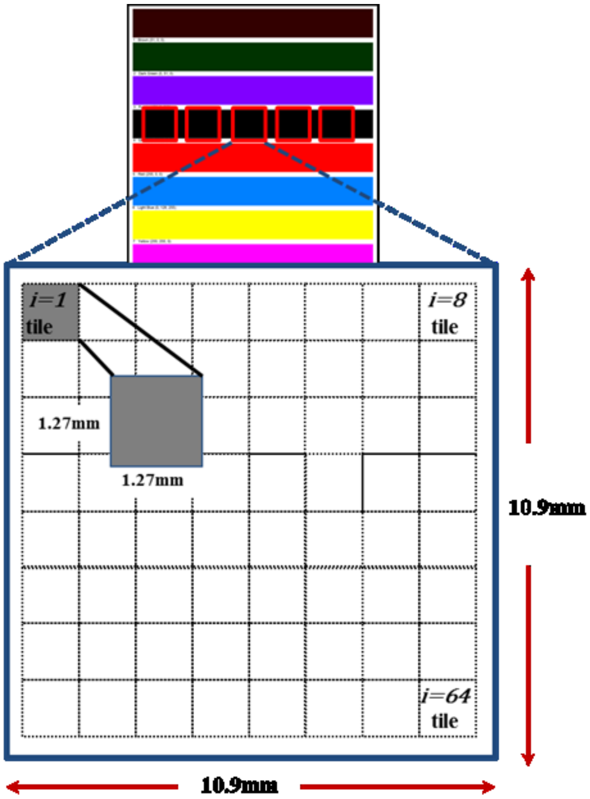


Figure 8. *Divided ROI into tiles*

2.4 JND_{mottle} Modeling

From the result of subjective assessment, we confirmed the relationship between the subjective score (*y axis*) and the printing OD (same as scanned lightness value) [Fig. 8 (a)]. It showed that Solid-Mottle defect was depended printing OD. From the test samples, if solid uniformity is perfectly similar (or solid uniformity is bad), observers were to give high mask to sample which has a low printing OD (same as scanned lightness value is high). Therefore, we could compute the JND (Just Noticeable Difference) of printing OD [*Eq. 3* and *Eq. 4*] to improve performance. And next, using *Parameter A* [*Eq. 2*] and JND_{mottle}, we obtained final Solid-Mottle score [*Eq. 5*].

After JND modeling, we can improve the Solid-Mottle metric as Fig. 9 (a) to Fig. 9 (b).

$$OD_{param} = Parameter\ A \times lightness \times 0.003 \quad (3)$$

$$JND_{mottle} = 1.869 \times {OD_{param}}^{0.647} \quad (4)$$

$$SolidMottle = \alpha + \beta \times JND_{mottle} \times Parameter\ A \quad (5)$$

$$SolidMottle' = \alpha + \beta \times\times Parameter\ A \quad (6)$$

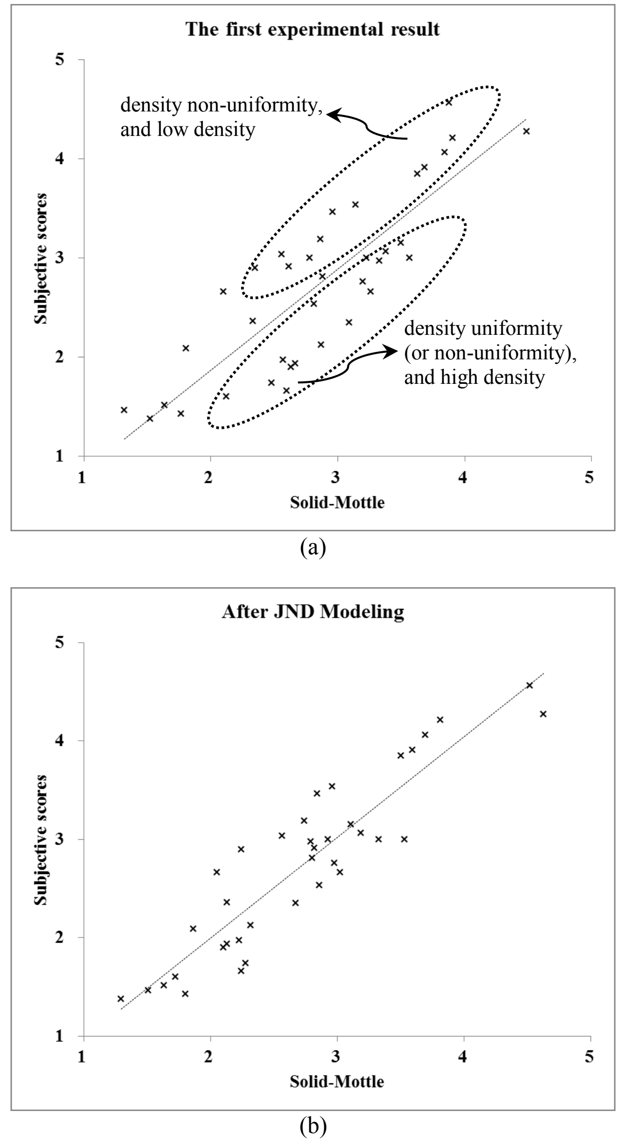


Figure 9. *JND_{mottle} compare capability before and after: (a) before (r is 0.85) [Eq. 6] and (b) after (r is 0.92) [Eq. 5]*

3. Verification for Proposed Method

We proposed two measuring method for Solid-Mottle: one is linear regression based; another is SVM based. Our metric is tested on 49 samples that are selected from nine different printing manufactures, which has various Solid-Mottle defects.

We used five-fold cross-validation for experiments. The samples of printed 49 pages are split into five groups by print image quality experts, and we have trained and tested each samples for five times. Each time, four of the five groups were used as training data and another group was used as test data. In the next subsection, experimental results of linear regression and SVM will be described in detail.

3.1 Linear Regression

Using five-fold cross-validation, the correlation coefficient r is to get as 0.92 and RMSE (Root Mean Square Error) [*Eq. 7*] is 0.34 between psychophysical experiment and quantified Solid-Mottle [Fig. 10].

$$RMSE(\theta_1, \theta_2) = \sqrt{E((\theta_1 - \theta_2)^2)} = \sqrt{\frac{\sum_{i=1}^{n}(x_1,i - x_2,i)^2}{n}} \quad (7)$$

Table 1. Weighting factors value

Weighting factors	α	β
Value	0.4726	1.14487

From the section 2.3, we conducted subjective assessment and computed weighting factor values using linear regression [Table 1].

Obviously, Solid-Mottle score of 3.0 or more was classified as unacceptable samples by print image quality experts. Thus, we can be to divide into pass or fail samples as standard score 3.0 and compute F_1*-measure* [*Eq. 8.1 – Eq. 8.3*]: F_1*-measure* is 0.82 [Table 2].

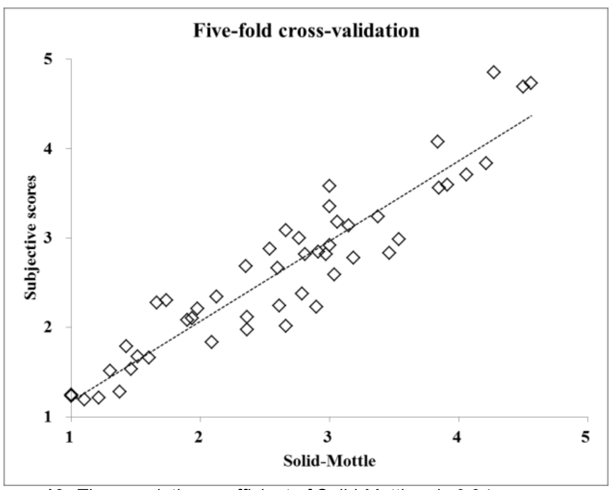


Figure 10. *The correlation coefficient of Solid-Mottle: r is 0.94*

$$F_1 = 2 \times \frac{precision \times recall}{precision + recall} \quad (8.1)$$

$$precision = \frac{True\ Positive}{True\ Positive + False\ Positive} \quad (8.2)$$

$$recall = \frac{True\ Positive}{True\ Positivie + False\ Negative} \quad (8.3)$$

Table 2. Validation result of Linear-regression

Solid-Mottle		The results of Linear-regression	
		pass	Fail
Visual grade	Pass	27	4
	fail	7	11

3.2 SVM

SVM is method of supervised learning, and we used three parameters that consist of *Parameter A*, JND_{mottle} and *lightness* for training.

F_1*-measure* is computed as 0.92, and the five-fold cross-validation result of SVM approach is shown in Table 3.

Table 3. Validation result of SVM

Solid-Mottle		The results of SVM	
		pass	Fail
Visual grade	Pass	27	3
	fail	1	18

4. Conclusion

In this paper, for the measuring of solid-uniformity, we proposed the Solid-Mottle new method for measuring based on psychophysical experiment. The Solid-Mottle is estimated by two weighting parameters *Parameter A* and JND_{mottle} that are determined by psychophysical experiment. From the experimental result, we confirmed the efficacy of our Solid-Mottle metric by five-fold cross validation and F_1*-measure*.

In addition, for a print image quality comparison data, such as print image quality benchmark, we used linear regression modeling to get an image quality score. However, for a product's quality testing, SVM approach is better than linear regression, because SVM's F_1*-measure* is higher performance than linear regression's F_1*-measure*: SVM's F_1*-measure* score is 0.92, linear regression's F_1*-measure* score is 0.82.

As future work, our study can be extended to different colors, such as cyan, magenta, red, green and blue.

References

[1] ISO, "13660:2001 (e) standard. Information technology – office equipment – measurement of image quality attribute for hardcopy output – binary monochrome text and graphic images", ISO, 2001.

[2] ISO, "24790:2007 (e) standard. Information technology – office equipment – measurement of image quality attribute for hardcopy output – binary monochrome text and graphic images", ISO, 2007.

[3] D. G. Ko, S. H. Song, Y. S. Bang, K. M. Kang, and S. W. Han, "Edge-Effect Method for Measuring in Laser-Printers", *The 31st International Technical Conference on Circuits/Systems, Computers and Communications Technical Program*, pp. 871 – 874, 2016.

[4] Y. Kipman, P. Mehta, K. Johnson, and D. Wolin, "A New Method of Measuring Gloss Mottle and Micro-Gloss Using A Line-Scan CCD-Camera Based Imaging System", *NIP17: International Conference on Digital Printing Technologies*, pp. 714-717, 2001.

[5] D. R. Rasmussen, "Tent-Pole spatial defect pooling for prediction of subjective quality assessment of streaks and bands in color printing", *Journal of Electronic Imaging*, 011017-1, 2010.

[6] D. R. Rasmussen, F. Gaykema, Y. S. Ng, K. D. Donohue, W. C. Kress, and S. Zoltner," W1.1 macro-uniformity", *SPIE-IS&T Electronic Imaging*, Vol. 7242-04, 2009.

[7] D. R. Rasmussen, E. N. Dalal, and K. M. Hoffman, "Measurement of macro-uniformity: streak, bands, mottle and chromatic variations", *SPIE-IS&T Electronic Imaging*, pp. 90-95, 2001.

[8] K. Y. Lee, Y. S. Bang, and H. K. Choh, "Quantification of Perceived Macro-Uniformity", *SPIE-IS&T Electronic Imaging*, Vol. 786704-1, 2011.

[9] A. H. Eid, E. Cooper, and M. N. Ahmed, "Characterization of Ghosting Defects in Electrophotographic Printers", *ICIP: IEEE International Conference*, pp. III453-456, 2007.

[10] M. Q. Nguyen, R. Jessome, S. Astling, E. Maggard, T. Nelson, M. Shaw, and J. P. Allebach, "Perceptual metrics and visualization tools for evaluation of page uniformity", *SPIE-IS&T Electronic Imaging*, Vol. 901608-1, 2014.

[11] K. Y. Lee, Y. S. Bang, and H. K. Choh, "Characterization of '2D noise' print defect", *SPIE-IS&T Electronic Imaging*, Vol. 7242-0M, 2009.

[12] Z. Y. Pizlo, Y. S. Bang, and J. P. Allebach, "Banding Assessment with Controlled Halftoning: The Ten Printer Experiment", *Journal of Imaging Science and Technology*, pp. 522-529, 2006.

[13] K. D. Donohue, C. Cui, and M. B. Venkatesh, "Wavelet Analysis of print defects", *IS&T PICS conference*, pp. 42-47, 2002.

[14] W. Wang, G. Overall, T. Riggs, R. Silveston-Keith, J. Whitney, G. Chiu, G, and J. P. Allebach, "Figure of Merit for Macro-uniformity Based on Image Quality Ruler Evaluation and Machine Learning Framework", *SPIE-IS&T Electronic Imaging*, Vol. 86530P-1, 2013.

[15] J. Suykens and J. Vandewalle, "Least squares support vector machine classifiers", *Neural processing letters*, 1999.

Author Biography

DAEGUN KO received his B.S. degree in Electronic Engineering and Computer Engineering from Yeongnam University, South Korea, in 2009, and he was a member of Samsung Electronics Software Membership from 2006 to 2009. The M. S. degree in Department of Digital Media and Communications Engineering from Sungkyunkwan University, South Korea, in 2016.

He is currently a researcher and developer at Samsung Electronics, South Korea. His research interests include image processing, pattern recognition, deep-learning and computer vision system for robots.

SUHAN SONG received his B.Sc. with honors in Electric Electronic & Computer Engineering from Hanyang University, South Korea, in 2006, from where he received his M.Sc. with honors in Electronics, Communications & Computer Engineering in 2008.

He is currently working as a researcher at Samsung Electronics. His current research focuses on improving automatic image defect detection on manufacturing processes using machine vision.

KI YOUN LEE received his B.S. and M.S.degrees from the Department of Electronic Engineering, Sogang University, South Korea, in 2005 and 2007, respectively.

He is currently working as a researcher at Samsung Electronics. His research interests include image quality evaluation, image processing, and computer vision system.

YOUSUN BANG received her B.S and M.S degrees in mathematics from Ewha Womans University, Seoul, Korea. She received her Ph.D. degree in the School of Electrical and Computer Engineering, Purdue University, West Lafayette, IN. USA in 2005. She joined in Samsung Advanced Institute of Technology in 2004, and she is now working as a principal engineer in Core Tech Group in R&D Team at Samsung Electronics Co. Her research interests include electronic imaging systems, color image rendering and processing, human visual systems, and image quality.

KIMIN KANG received his Ph.D. degree in Electrical Engineering from Inha University, South Korea, in 2001. He joined in Samsung Electronics Co. Ltd in 2001 and has researched and developed the algorithms and the pipelines related to the image enhancement and the quantitative quality diagnosis with vision system. Now, he develops the documents workflow solutions embedded in the copier machines based on the scene analysis and the optical character recognition.

SEONG WOOK HAN received received the B.S. degree in electronics engineering from Yonsei University, Seoul, Korea, in 2000, and the M.S. degree in electrical and electronics engineering from Yonsei University, Seoul, Korea, in 2002. From 2002 to 2004, he was a research engineer at on Timetek Inc., Seoul, where he worked on video compression, video transmission, and pre/post processing for digital broadcasting systems. In 2009, he received his PhD degree in electrical engineering from Purdue University, West Lafayette, IN. Since January 2009, he has been with Samsung Electronics Co. Ltd., Suwon, Korea, developing algorithms for electronic imaging systems. His research interests include electronic imaging systems, color processing, video coding, image/video analysis and image enhancement.