Standardization of Perceptual based Gloss and Gloss Uniformity for Printing Systems (INCITS W1.1)

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Abstract

To address the standardization issues of perceptually based image quality for printing systems, ISO/IEC JTC1/SC28, the standardization committee for office equipment chartered the W1.1 project with the responsibility of drafting a proposal for an international standard for the evaluation of printed image quality. One of the W1.1 task teams is chartered to address the issue of "Gloss and Gloss Uniformity". This paper summarizes the current status and technical progress of this ad hoc team including test target creation, psychophysical experiments toward gloss perception, gloss measurement variability and some initial work on microgloss measurement.

1. Introduction

ISO/IEC JTC1/SC28, the standardization committee for office equipment of which INCITS W1 is its United States representative, is organized to address the standardization issues of perceptually based image quality for printing systems [1]. The INCITS W1 chartered the W1.1 project to draft an international standard proposal to assess the printed image quality that is appearance based and applicable to systems incorporating gray-level and color imaging technologies. They include text and line quality, macro-uniformity, gloss and gloss uniformity, and color rendition [1,2,9]. The gloss and gloss uniformity attributes, which consist of gloss value, within-page gloss uniformity, page-to-page gloss uniformity, differential gloss and gloss artifacts, will be addressed in this paper. This paper describes the current technical progress and status of this ad hoc team in relation to test chart creation, round-robin objective measurement study of the differential gloss attribute. The current work involving nineteen paper and technology combinations includes psychometric scaling of objectively measured differential gloss samples, psychometric scaling experiment defining the just noticeable difference of nearly adjacent gloss samples as a function of overall gloss, and some initial work on microgloss measurements

of different microgloss artifacts.

The light contributing to our visual system on a reflective print can be formulated as the following equation [3]:

$$L_\lambda(\hat{\theta}_r) = \int R_\lambda(\hat{\theta}_i, \hat{\theta}_r) L_\lambda(\hat{\theta}_i) \cos\theta_i d\omega_i \qquad (1)$$

where $L_\lambda(\hat{\theta}_i)$ and $L_\lambda(\hat{\theta}_r)$ represent the local incident and reflection light with angle $\hat{\theta}_i = (\theta_i, \phi_i)$ and $\hat{\theta}_r = (\theta_r, \phi_r)$. λ emphasizes that the light wavelength is one parameter controlling the above equation and $d\omega_i$ represents the solid angle of the incident light. R_λ is the *Bidirectional Reflection Distribution Function*, BRDF, of the perceived object characteristics. Color is perceived away from the specular angle where R_λ has only insignificant variation relative to $\hat{\theta}_i$ and $\hat{\theta}_r$; Hence, it is sufficient to describe L_λ in the spectrum domain. However, the perceived gloss will be affected by the light wavelength λ as well as its angles $\hat{\theta}_i$ and $\hat{\theta}_r$. As a result, unlike color which can be compressed into a three dimensional measurement, it is very difficult to derive an universal gloss measurement based on simple algebraic functions [4].

There are two facets concerning quantifying gloss: the physical gloss measurement and the visual gloss model. Regarding the physical measurement, since ASTM already approved several gloss measurements such as D523-89 and D3923-93, it is necessary to design test targets to quantify the measurement variability among measuring devices [5]. Moreover, like the target used in a color management system to quantify the color gamut of the tested system, the designed gloss test targets need to be able to explore the gloss characteristics of an imaging system. In terms of the visual gloss model, the challenging task is to identify attributes affecting visual gloss and correlate with human perception. In this paper, we summarize two psychophysical experiments dealing with the ratio scale of the perceived differential gloss and the differential gloss threshold under normal viewing conditions. At last, we will describe the on-going investigation on the microgloss measurement, which is found to modify the overall gloss perception.

2. Gloss Test Target Creation

The requirement of this target is to capture the salient points of the gloss characteristics of the intended imaging system. This test target can be adopted in the following round-robin experiment quantifying the gloss measurement variability between laboratories as well as the attributes of differential gloss and gloss uniformity. Because that the major contribution to gloss measurement is the first surface light reflection determined by the outmost surface roughness [3], we showed that a *Roughness Mixture Model* can describe a significant portion of measured gloss in terms of colorant coverage [6,7]. Adopt this model as the *a priori* model, and a gloss patch selection algorithm was proposed to identify those salient points by using the support vector regression to model the difference between the measurement and the proposed a priori model [6]. This algorithm first compresses the variation among different paper and processes into the first three principle components using the singular value decomposition, and then a set of support vectors are identified using the support vector regression based on 1-norm penalty function. We demonstrated that the error between the predicted and measured gloss can be significantly reduced based on the selected patches. A test target as shown in Figure 1 with forty patches for differential gloss is proposed based on this algorithm.

The objective of designing a test target to measure gloss uniformity is different from that of quantifying gloss characteristics of a system. The chosen point should possess high gloss variability relative to the change of the amount of colorant because it affects the outmost surface roughness and the overall reflectance coefficient. That is, the salient points for quantifying gloss uniformity are the ones of which gradient magnitude is large. Because the a priori model and the support vector regression both are expressed as analytic functional forms, their derivative can be easily obtained. Note that the most sensitive point might be different depending on the combination of paper and printing process, and our objective is to have one test target to be applicable to most cases. As a result, we can first identify salient points for sample prints and apply a hierarchical clustering technique to reach the desirable number of patches. The gloss uniformity is estimated via the triangularization principle where one colorant combination is printed at three locations to exhibit gloss variation among them. Based on these principles, Figure 2 is the designed test targets for quantifying gloss uniformity within a page.

3. Gloss Measurement Variability

ASTM has approved various specular gloss measurements which mainly differ in their illumination angles, including 20, 30, 45, 60, 75 and 85 degree specular gloss measure-

Figure 1: *NCITS W1.1 Differential Gloss test target V1.0*
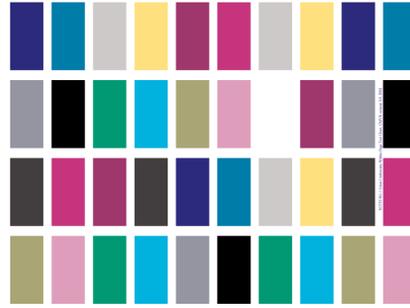

Figure 2: *NCITS W1.1 Gloss Uniformity test target V1.0*

ment [5]. Among them, 20, 60, 75 and 85 degree gloss measurement are the most popular ones in the printing industry to quantify the gloss on a reflective print. These defined gloss measurement can be summarized by the following equation:

$$Gloss = 100 \frac{\Phi_{\theta, R_\lambda^{Sample}}}{\Phi_{\theta, R_\lambda^{Reference}}} \qquad (2)$$

where $\Phi_{\theta, R_\lambda^{Sample}}$ and $\Phi_{\theta, R_\lambda^{Reference}}$ are the reflection influx of the sample and the reference surface through the detector aperture. The reference surface is a mirror-like black glass with reflective index being 1.567. However, because of the variance in the manufacturing process, the reported gloss reading among gloss meters will exhibit a certain degree of variation. A round-robin experiment adopting the test target as shown in Figure 1, which consist of 19 paper and technology combination, 5 companies and over 45,000 measurement (including 5 angles, 40 patches, 3 repetitions), is designed to capture this measurement variation. Its attempt is to quantify the gloss measurement variability based on the same type of gloss meter (the **BYK Gardner** gloss meters are used in this experiment because of their wide availability). Contribution from companies and research institutions are needed to address the measurement variability across different gloss meter manufacturers.
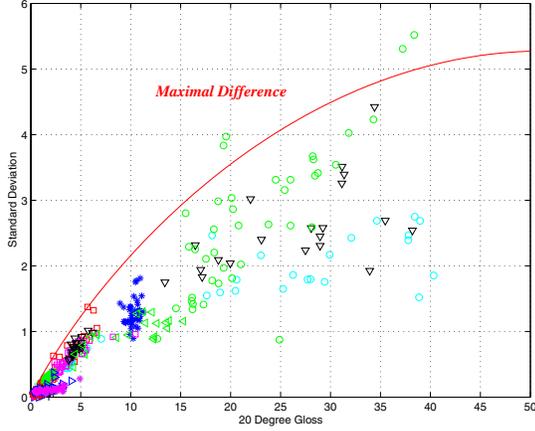
Figure 3: *G20 variation and estimated measurement uncertainty*
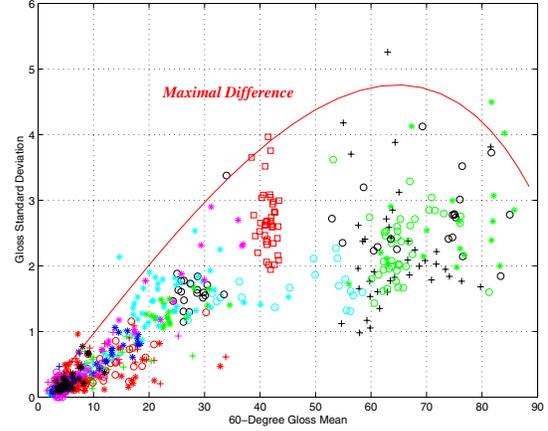
Figure 4: *G60 variation and estimated measurement uncertainty*

We can deduce from equation 2 that all gloss measurement should agree at two points, i.e. 0 and 100. Hence, we assume that the variation at these two points are zero. The Z-score transformation is first applied to the raw gloss reading to compensate this measurement variation nonuniformity. Assuming the measurement for each print sample being a random sequence with a gaussian distribution, the sufficient statistics to completely describe this random sequence is its mean, μ, and standard deviation, σ, which can be easily estimated using the maximum likelihood estimation. We then apply the *Probit* analysis to correlate between the estimated mean $\hat{\mu}$ and standard deviation $\hat{\sigma}$. Figure 3 and 4 show the variation in G20 and G60 gloss measurement from 19 paper and printing technology combinations, and the associated gloss measurement maximal differences, δ_{g20}^{max} and δ_{g60}^{max}, as listed in the following:

$$\delta_{g20}^{max} = 21.8(\frac{g_{20}}{100})^3 - 39(\frac{g_{20}}{100})^2 + 24.3(\frac{g_{20}}{100}) + 0.08 \quad (3)$$

$$\delta_{g60}^{max} = -20.7(\frac{g_{60}}{100})^3 + 14(\frac{g_{60}}{100})^2 + 7.2(\frac{g_{60}}{100}) + 0.06 \quad (4)$$

According to ASTM D523, the maximal acceptable differences between laboratories on painted panels is 6.4 and 3.5 for G_{20} and G_{60} respectively [5]. Compared with the maximum allowable difference on printed patches in our experiment, 5.3 and 4.7 for G_{20} and G_{60} respectively, we can conclude that they reach good agreement.

4. Gloss Detectability

Because the image quality is subjective, it is necessary to verify that the objective gloss measurement is correlated with the subjective assessment. More importantly, it is necessary to find out whether the proposed measurement composes a simple linear space for human visual gloss sensation. However, because of the adaptation mechanism of human beings, like the proposed color spaces, it was shown that there exists a nonlinear relationship between the gloss perception and gloss measurement. Hence, the first basic question is determining the variation of the differential gloss visual threshold relative to the gloss measurement. In addition to the overall gloss perception, differential gloss is another attribute affecting image quality [1]. A differential gloss perceptual scale experiment was conducted and explained in the following section to identify its contributing factors and their relationship with the perceived differential gloss.

Since many factors will affect gloss perception such as luminance, color and microgloss, it is necessary to limit the sample space to control these factors. A psychophysical experiment was conducted to investigate the differential gloss threshold variation (or so-called the just noticeable difference) [7]. The method of constant stimuli with forced choice procedure is selected for this experiment [5]. Observers are asked to evaluate samples at the normal viewing position under standard lighting condition, *D50*, and they can freely tilt the samples to acquire overall gloss sensation. However, they are not allowed to move away from this viewing position. Two samples being compared are placed in the immediate juxtaposition. Observers are asked to select the sample with higher perceived gloss. Groups of samples with G_{60} reading at 10, 20, 30, 45 and 60 are chosen. They all have similar color to avoid the color/luminance effect on perceived gloss. Moreover, print samples are chosen to have similar surface structure to reduce the microgloss effect. As a result, we can deduce that the specular gloss dominates the entire gloss perception. Assuming the *Gaussian psychometric model* is able to describe the perceptual gloss, the relationship between the measured gloss and the gloss JND can be fitted via the

Power Law. For samples with 100% black toner coverage, the associated power function is estimated as following [7]:

$$JND_{G_{60}} = 0.14(G_{60})^{0.96} \sim 0.14(G_{60}). \qquad (5)$$

Equation 5 indicates that, within the investigated gloss range, the gloss perception follows the *Weber's Law*. This should not be surprising since gloss perception is very similar to light intensity perception, and the *Weber's Law* has been found to be valid within the moderate light intensity range. Note that two cyan and two magenta patches with G_{60} being 20 and 50 were also tested for their gloss JNDs, and we found that, although the estimated JNDs at approximately G_{60} being 20 is close to the number predicted by Equation 5, discrepancies exist at high gloss range. Therefore, it remains as one of our future research topics to correlate between color/luminance and gloss.

5. Differential Gloss Perceptual Scale

The objective of this experiment is two fold: to identify the factors contributing to differential gloss perception, and to answer whether the algebraic gloss measurement difference correlates with the perceived differential gloss. To avoid the image content influence, we decided to use the designed differential test target in Figure 1 as our evaluation print in this pilot experiment. The set of evaluation prints contains seventeen prints with various types of printers and paper used in the previous round-robin experiment. This experiment was conducted under the *graphic art standard viewing condition* with overhead light offering well-defined illumination source, and it can be separated into two parts:

1 Five Anchor prints are selected with similar gloss behavior but different amount of measured gloss difference. The magnitude estimation psychophysical experiment was conducted to obtain a ratio scale.

2 Observers were instructed to place remaining prints according five anchor prints and assign a number describing the perceived differential gloss relative to the scales of anchor prints.

Among all 17 print samples, there exists four samples of which gloss characteristics versus colorant coverage is different from others. Their measured gloss decreases monotonically relative to the amount of colorant coverage while the lowest measured gloss for other samples appears at the patches with medium coverage. A pilot experiment was conducted to investigate the influence of this difference toward the perceptual gloss scale where patch 5 and 6 were selected for evaluation under the same
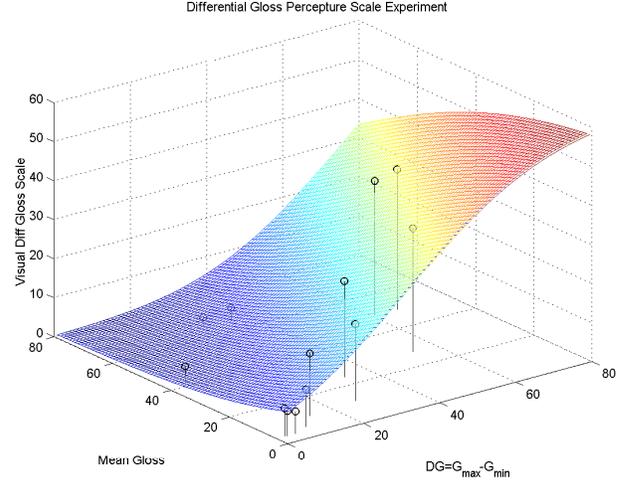

Figure 5: *Ratio Scale for anchor prints and verification prints*

viewing condition. Observers were asked to quantify the perceived differential gloss between two patches. Two print samples, *Xerographic NC60 LustroLaser Coated* and *Mohawk Navajo Regular Gloss*, are rated as having comparable perceived differential gloss between two patches with the algebraic gloss difference being 31.2, 35.9 and -10.4, -21 in terms of (G_{60}, G_{85}) respectively. The first print exhibits the normal gloss characteristics while the gloss is monotonically decreases relative to the colorant coverage on the second print. This experiment suggests that there exists correlation between perceived differential gloss and the luminance.

Excluding those four prints with monotonically decreasing measured gloss relative to colorant coverage, we apply the *Probit Analysis* to the remaining prints sample. Two attributes that we believe affect the perceived differential gloss: the algebraic gloss difference and the overall glossiness [2] . First, $DG = G_{max} - G_{min}$ is proposed to quantify the dynamic range of the measured gloss on a print sample. Secondly, the gloss detectability experiment in the previous section demonstrates that the gloss JND follows the *Weber's Law*. That is, larger gloss difference is needed to be seen when the print is glossier. Therefore, the perceived differential gloss will become smaller when the whole print becomes glossier even though the DG value stays the same. As a result, we adopt the $g_m = (1/40) \sum_{i=1}^{40} G_{60}[i]$ to quantify the overall glossiness of that print. Figure 5 shows that averaged rating assigned by all observers and the corresponding fitted surface. Let f_p be the *Cumulative Probability Distribution Function* as following:

$$f_p(x) = 100 \int\limits_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} e^{-\mu^2/2} d\mu \qquad (6)$$

and the regressed visual differential gloss scale, S_g, in Figure 5 is:

$$f_p^{-1}(S_g) = -1.2 + 3.7(DG) - 2.1(g_m). \qquad (7)$$

The small *p value* of the *Probit Regression* indicates a satisfactory agreement. This model suggests that the perceived differential gloss will increase nonlinearly with respect to the increasing DG value, but it will decrease when the overall glossiness increases. Future research is needed to include the monotonically decreasing gloss characteristics.

6. Microgloss Measurement

The light reflection model as shown in Equation 1 indicates that the BRDF of an object determines the reflected light. As a result, unless the surface of the object is very smooth, the fine structure on the surface inevitably will be perceived by observers. The gloss perception discussed in previous sections falls into the macroscopic case where it is simplified as *gloss*. *Microgloss* is dedicated to represent the fine structure in the perceived gloss. The occurrence of microgloss artifacts can be quite objectionable, detracting from overall image quality, as the observer views a document at varied orientation and illumination settings. Studies have indicated that perceived differential gloss and even average gloss preference can be significantly altered by the presence of microgloss artifacts in the image regions [7,9].

Many factors, such as substrate porosity, toner/ink blistering, process heat/pressure inconsistencies, etc., may contribute to the existence of microgloss in a printing system. Microscopically, the object's surface can be considered as being composed by many facets with their normal vectors pointing to different directions. Hence, if the normal vectors are completely random, the reflected light should be isotropic with no distinguished fine structure; However, when the normal vectors are spatially correlated, certain fine structures will become apparent when the viewing angle is very close to the specular angle of those facets. For example, the normal vectors along the toner/ink blistering exhibit strong spatial correlation, which, in turns, contributes to a significant microgloss appearance.

Commonly available gloss measurement instruments are not designed to capture these effects, but only to provide an average gloss measurement of the image region - typically on the order of several square millimeters. It is conceivable that one may apply such an instrument to acquire gloss uniformity information by making multiple measurements at discrete regions, but this is a cumbersome approach and, in fact, objectionable microgloss artifacts can occur at spatial frequencies too high to be resolved with these instruments. Various researchers have described systems intended to capture 2-D specular imagery from print samples [8,10]. Such a system, configured by **ImageXpert Inc.**, has been applied in an attempt to capture the various micro-gloss artifacts from a set of sample prints submitted by the W1.1 team. At present no attempts have been made to quantify the micro-gloss artifacts images obtained with this instrument.
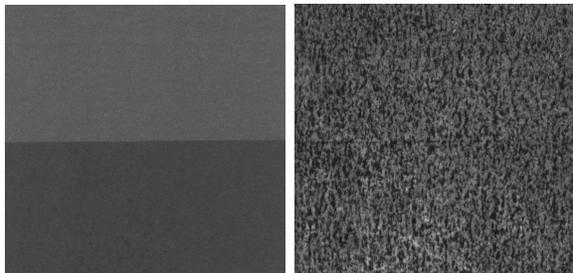

Figure 6: *Density Scan*   *Figure 7*: *Microgloss Scan*

Microgloss can be further classified into 1D and 2D cases. One example of captured 2D microgloss is shown in Figure 7. Figure 6 is the corresponding density scan consisting of a green patch on the top half and blue patch on the bottom half. The perception variation is similar to what is shown in these two scans. At normal viewing distance with viewing angle being less than 20 degrees from perpendicular, the color patches appear smooth without much noticeable change in luminance or hue. When the page is tilted to an angle where the specular gloss is significant, the variation in the gloss becomes apparent. Furthermore, two sets of print samples with cyan, magenta, yellow and black are measured. Although the average of microgloss reading is found to linearly correlate with the gloss meter reading with R^2 statistics being over 93%, each sample possesses different microgloss structure. This indicates that it is impossible to quantify the amount of microgloss existing on a print sample using the current gloss meter. Moreover, the microgloss reading is found to be independent from the luminance of each sample, which is illustrated in Figure 6 and 7. As a result, we can conclude that this microgloss measurement can successfully capture gloss variation on a print sample without being affected by its luminance reflection variation.

As noted previously, the microgloss can be explained by the microscopic facet hypothesis; Hence, they are usually anisotropic unless the distribution of the normal vectors of surface facets is *iid* (independent and identical distribution). That is, depending on the illumination and viewing angles, different surface structures will appear on the captured microgloss images. For example, a patch with a fine line artifact is measured with the illuminating/perceiving plane being parallel and perpendicular to the artifact direction as shown in Figure 8 and Figure 9. The gloss streak is very obvious on the scan along the streak direction, but it
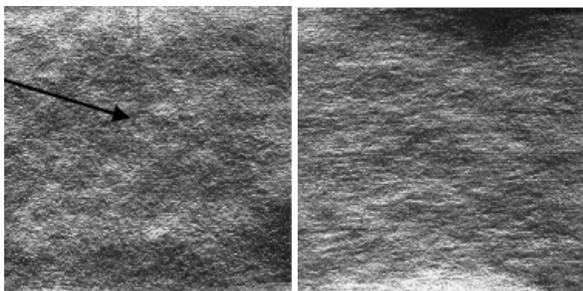
Figure 8: *Fine Gloss Streak Orientation 1*   *Figure 9*: *Fine Gloss Streak Orientation 2*

almost disappears in the other scan. This can be explained by the situation where the first surface reflection can be easily blocked in the perpendicular direction but traverse freely in the parallel direction when the fine gloss streak is contributed by a fine scratch line on the surface of the print sample. Similarly, the microgloss measurement varies depending on its scanned direction relative to the paper fiber grain. However, when the scale of the gloss artifact is relatively large as seen in Figure 10 and Figure 11, both gloss line artifacts are observable from both illumination directions. However, the magnitude of the reflected light is different as seen from the different luminance of both images, and this observation confirms our hypothesis that the microgloss is usually anisotropic.

Because microgloss is relatively new topic, further research is needed to design a test tool robust enough to capture gloss images at various illumination angles and amounts of specular gloss levels. In general, attempts at capturing the 2-D specular image to enable measurement of the micro-gloss artifacts have been encouraging. With attention to specific illumination/capture angle geometries, including solid angle restriction, this image information should be attainable. With this available, concentrated efforts on quantification of this gloss sub-attribute may ensue, which must occur in conjunction with psychophysical studies to insure appropriate response to the micro-gloss artifacts.
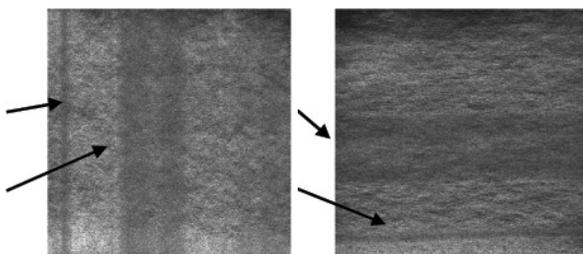

Figure 10: *Gloss Streak Orientation 1*   *Figure 11*: *Gloss Streak Orientation 2*

7. Conclusion

The current status and technical progress of this W1.1 ad hoc team are summarized in this paper, including test target creation, psychophysical experiments toward gloss perception, gloss measurement variability and some initial work on microgloss measurement. We also indicate the future research direction toward understanding gloss and gloss uniformity visual attributes, and we look forward to the contribution from all companies and research institutions.

8. References

1. Eric Zeise and Norman Burningham, "Standardization of Perceptually Based Image Quality for Printing System", *IS& T NIP18*, pp.698-702, (2002).
2. Yee Ng, and Chunghui Kuo and Jeffrey Wang, "Gloss Uniformity Attributes for Reflection Images", *IS& T NIP17*, pp.718-722, (2001).
3. J. Condek, G. Meyer and J. Newman, "Wavelength Dependent Reflection Function", *SIGGRAPH'94*, pp.213-220, (1994).
4. R. Hunter and R. Harold, "The Measurement of Appearance, Second Ed.", *John Wiley*, (1987).
5. ASTM Committee, "ASTM Standards on Color and Appearance Measurement, Six Ed", (2000).
6. Chunghui Kuo, Yee Ng and Jeffrey Wang, "Gloss Patch Selection based on Support Vector Regression", *PICS2002*, pp.121-125, (2002).
7. Chunghui Kuo, Yee Ng and Jeffrey Wang, "Differential Gloss Visual Threshold under Normal Viewing Conditions", *IS&T NIP18*, pp.467-470, (2002).
8. J. Arney and J. Michel, "Instrumental Analysis of Gloss and Microgloss Variations in the Printed Images", *PICS2002*, pp.126-129, (2002).
9. P. Swanton and E. Dalal,"Gloss Preference for Color Xerographic Prints", *J. Imag. Sci. & Tech.*, 40, 158, (1996).
10. 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", *IS&T NIP17*, (2001).

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