Measurements, Simulation, and Reconstruction of Gonio-Spectrum Reflectance in Electrophotography

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Abstract

The relation between three-dimensional forms and Gonio-spectrum reflectance distributions of electrophotographic prints are studied. A light propagation simulation tool using Monte Carlo code is developed for analyzing light behavior in electrophotography prints. The simulated results of Gonio-spectrum reflectance distributions qualitatively correspond with measured datum. Based on comparisons between simulated and measured values, effects of base sheet's specular reflections on gloss values within electrophotography prints are estimated.

Moreover, the prototypes of interactive "HANDHELD PRINT" viewing systems are developed. They can show what look electrophotographic print has, whether from where viewers look or how viewers handle the print. By using the system, electrophotographic prints can be examined and evaluated in various conditions.

Introduction

The most remarkable feature of electrophotographic prints is inhomegeneous "image look"[1-4]. Fig.1 shows variations of three-dimensional surface form in different tones. Those surface and inner conditions makes various properties in of the electrophotographic prints, such as color and gloss. Also print's appearance changes with the positional relation between the print and viewers. Fig.2 shows examples of variable "image look" in electrophotography. Both prints (a: a high gloss print on a rough surface paper, b: low gloss print on rough paper) change their appearance, with changes of the relative position between light, viewer, paper itself, and how viewer hold it and bend it. Especially in high gloss print on rough surface paper case, reversal effects of gloss are significant.

Gonio-Spectrum Reflec-tance Distribution

Gonio-spectral reflectance distribution measurement is the most suitable measuring method for understanding print's "image look". Fig.3 shows a diagram of the procedure and an example of measured Gonio-color reflectance distribution (in section). A material to be measured is put. And, a light source and a detector are located and spectrum color is measured. By repeating to change the light and the detector's positions and measure, spectrum color distributions are obtained.

Fig.4 show several examples of measured datum (surface forms and Gonio datum) in three different tones in two fixing conditions and a base paper. In Fig.4 a light illuminate from 45 degree from zenith direction, and the color distribution of specular lights are easily understood.

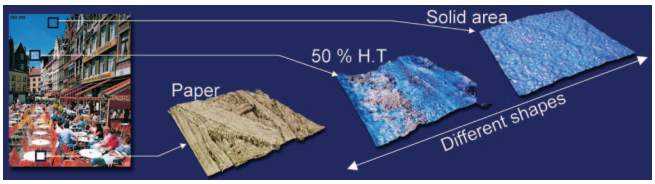
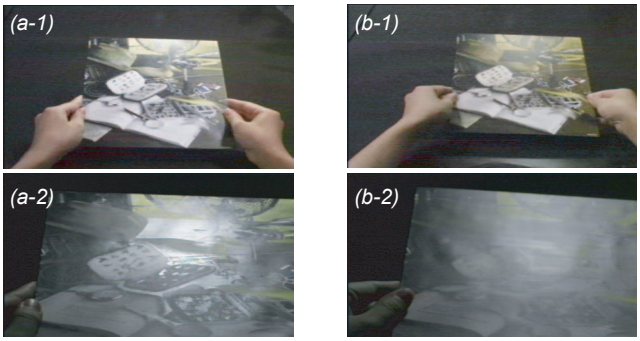


Figure 1. Examples of surface forms of electrophotographic print in different tones



(a) High gloss electrophotographic print *(b) Low gloss electrophotographic print*

Figure 2. Views of electrophotographic prints when they are read with handheld

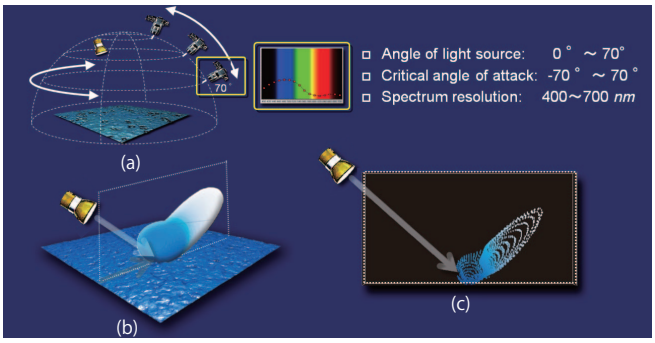


Figure 3. Three-dimensional Gonio-spectrum reflectance distribution

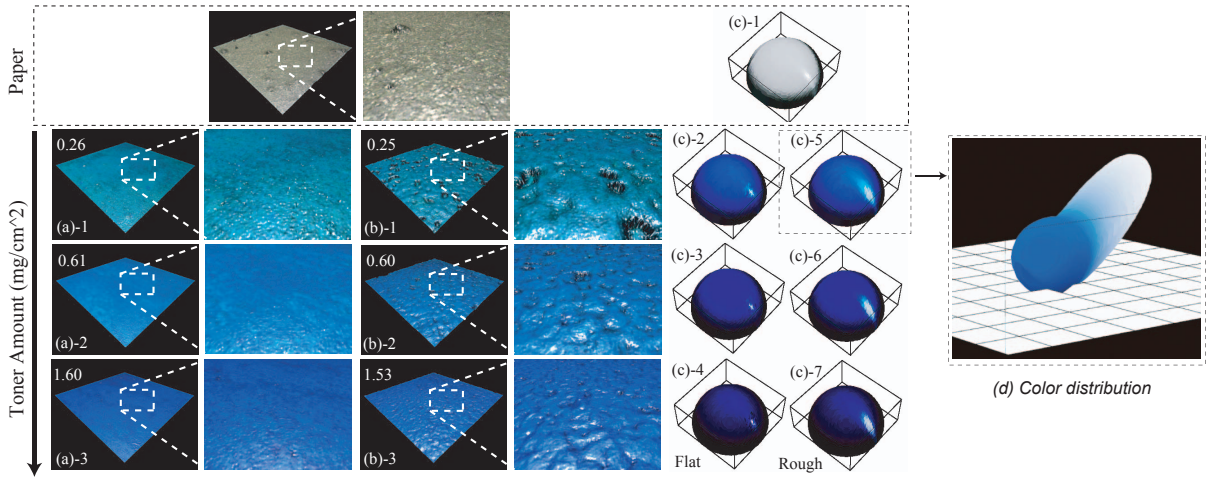


Figure 4. Measured surface form and color distribution (three-dimensional Gonio spectral reflectance) of electrophotographic prints

Light Propagation Simulation using Monte Carlo Code

To reveal relations between electrophotographic print's forms, inner conditions, and "image look"s, we developed a light propagation simulation tool using Monte Carlo code. Fig.5 shows the procedure of the light propagation simulation.

Computational area is classified following three domains;

Air domain: Light (as a Monte Carlo trial's) run strait 100 *nm* step.

Coloring layer domains: Lights change their color spectrum according to the specified absorbed fraction under Lambert-Beer's equation. Additionally, according to the scatter coefficient, lights change the direction of movement. As, scattering direction distribution, Henyey-Greenstein function is used. Absorbed fractions and scatter coefficients are experimentally-acquired. Also, measured surface forms of prints are used in simulations.

Paper domain: On a paper surface, reflections of lights are decided in probability by using premade Bi-directional Reflectance Distribution Function (BRDF). The paper BRDF is acquired from Gonio-spectrum measurements, and, the BRDF of paper surface is simplified using Phong model.

At every boundary between different domains, light propagation direction is decided under Fresnel's and Snell's law. Fig.6 shows examples of light propagation path in Monte Carlo simulation tirals. By accumulating those trials, Gonio-spectrum color distribution is simulated.

Simulated Gonio-Spectrum Color Distribution

Examples of simulated Gonio-spectrum color distribution are following;

Screened gradation examples:

Fig.7 shows simulated results of a paper, a halftone with line screen, and a solid tone. These results shows that changes of

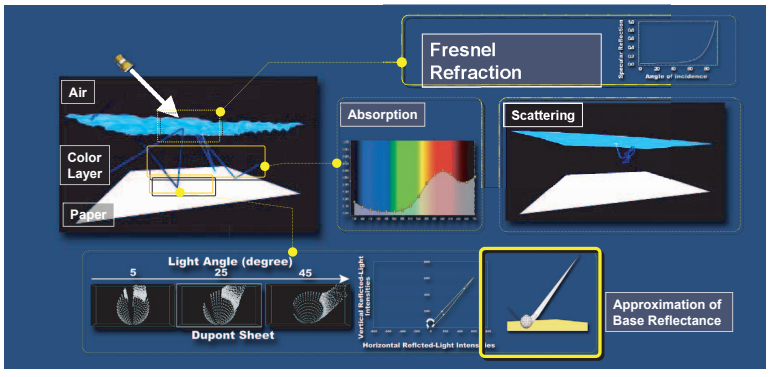
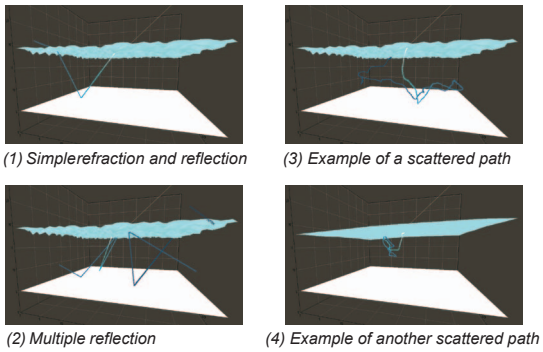


Figure 5. Procedure of light propagation calculation using Monte Carlo simulation



(1) Simplerefraction and reflection

(3) Example of a scattered path

(2) Multiple reflection

(4) Example of another scattered path

Figure 6. Example of light paths of light propagation simulation

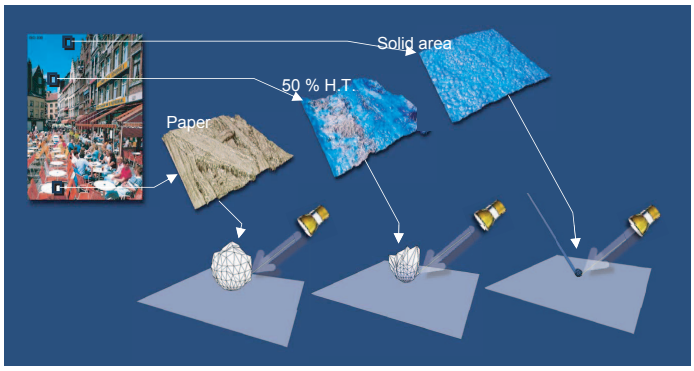


Figure 7. Calculated results of screened(halftoned) graduation print patterns by employing the Monte Carlo light propagation simulation

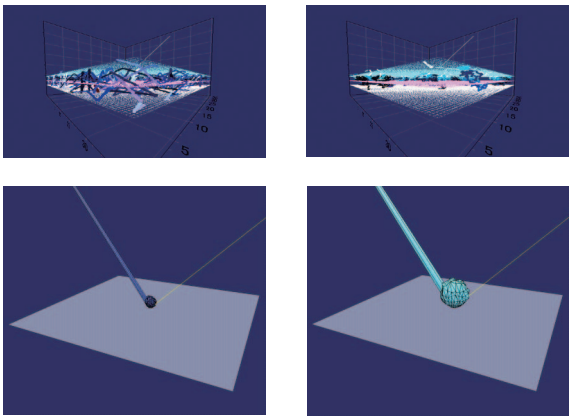


Figure 8. Example of simulation result of multi layer prints

45/0 spectrum ("color" towards zenith direction) and gloss are qualitatively coincident with actual characteristics of electrophotography print. For example, increase of color density with toner amount, and the reversal effect of gloss are confirmed.

Multi layered color in different fixing conditions examples;

Fig.8 shows results of multi layered secondary color (upper layer: cyan, lower layer:magenta) prints in different two fixing conditions. (a) shows the result in case of well fixing condittion (toner layers have low scatter coefficients). (b) shows un-well fixed condition (toner layers have high scatter coefficient). In (a), it color blue as well composed secondary color of cyan and magenta. In (b) case, the color of print is made from only upper cyan layer, because of light scattering.

Non-Screened gradation prints examples;

Fig.9 shows non-screened gradation (analogue tones) area examples in two different fixing conditions. Measured print surface forms are shown in upper row. Measured Gonio-color reflectance distributions (in section) are shown in middle row. Simulated Gonio-color distributions are shown in lower row. The simulated results qualitatively correspond with measured datum.

, in case of non-screened gradation prints with two fixing conditions. The simulated results qualitatively correspond with measured values (for example, most high gloss tone).

To estimate effects of base sheet's specular reflections on gloss values, simulation experimentation are calculated. Fig.10 shows simulated results in the case of Fig.9 (f-1) with (a) / without (b) the base sheet's specular reflections. Based on the results, it is confirmed that effects of paper gloss is considerable in low density tones. By using the system, electrophotographic prints can be examined and evaluated in various conditions, whether from where viewers look or how viewers handle the print.

Reconstruction System of Electrophotography Print "Image Look"

Several types of reconstruction system of electrophotography print "image look" are developed for predicting and estimating image quality. The systems can be show how prints look like from arbitrary view point. Fig.11 shows QuickTimeVR format examples

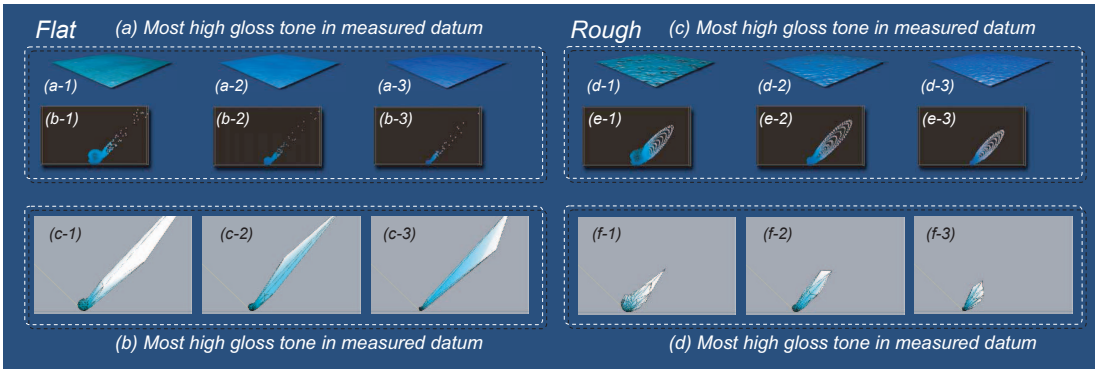
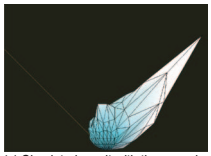
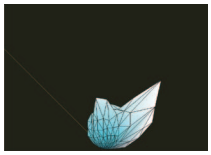


Figure 9. Examples of surface forms, measured spectrum reflectance distribution and simulated BRDF



(a) Simulated result with the specular reflection of paper surface



(b) Simulated result without the specular reflection of paper surface

Figure 10. Simulated result with/without the specular reflection of the base sheet

using our first system[1]. Fig.12 shows the demonstration of "print look viewing system" using laptop pc's attitude sensing system.

Summary

The relation between three-dimensional form and Gonio-spectrum reflectance of electrophotographic prints and papers are studied by using Monte Carlo light propagation simulation tool we developed. Effects of specular reflection of base sheets to gloss values of electrophotography prints are estimated.

Reconstruction system of electrophotographic print's "image look" for application of predicting and evaluating "image look", are developed.

References

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[2] J. Hirabayashi, T. Tanoue, S. Ishida, M. Ito, K. Ogawa, "Analysis of Electrophotography Surface Form and Color", Imaging Conference Japan 2006 , pg. 271-274. 2006.

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Author Biography

Jun Hirabayashi received his B.S. and M.S. degrees in science from Kyoto University in 1992 and 1994. He joined CANON in 1994. He has been working on the field of Electrophotography and researching color science. he received the paper of the year in 2000, and the prize of fellowship of Imaging Society of Japan in 2003.

Megumi Ito received her B.S. and M.S. degrees in Materials Science and Technology from Tokyo University of Science in 2001 and 2003. She joined CANON in 2003. She has been working on the field of Electrophotography and researching color science. She received the prize of fellowship of Imaging Society of Japan in 2007.

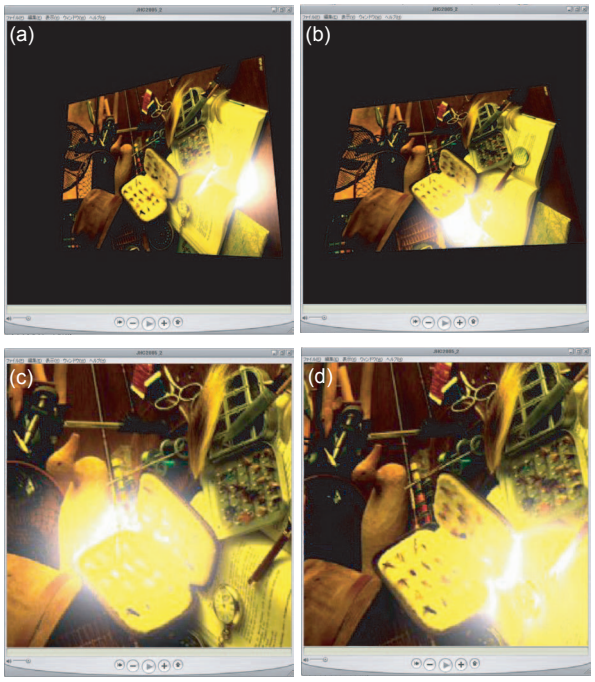

Figure .11 Rendered three-dimensional electrophotographic print image using QuicktimeVR Object movie format

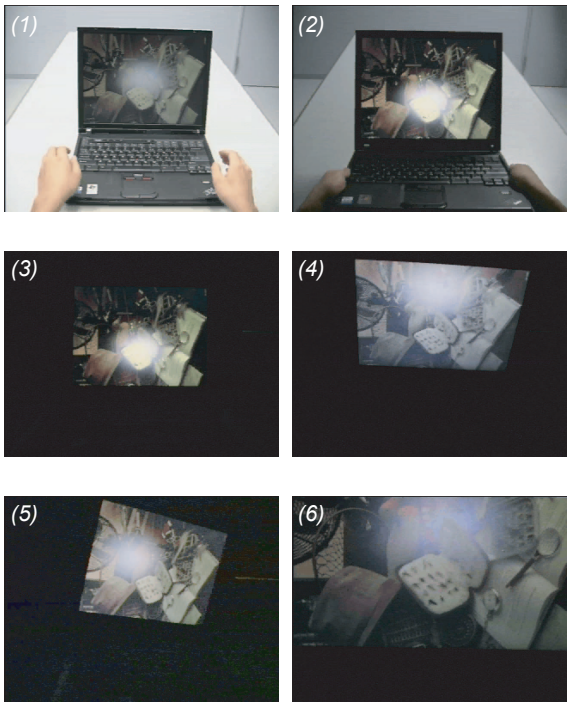

Figure 12. Demonstration of "HANDHELD PRINTS" prototype system