中国印刷与包装研究 2014年第6期（第6卷）
CHINA PRINTING AND PACKAGING STUDY Vol. 06 No. 6 2014. 12 pp. 60-64

Print-Based Visual Security Features

HERSCH Roger D
(*Ecole Polytechnique Fédé rale de Lausanne* (*EPFL*) , *Lausanne* 1015 , *Switzerland*)

Abstract Security features ensuring the authenticity of banknotes, checks, identity documents, diploma and business documents as well as of valuable goods are of high importance in today's society. We briefly describe three security features that rely on color prediction models. The color prediction models are used both in forward mode to predict a color from given surface coverages of the inks and in inverse mode for computing the surface coverages of the inks in order to create a desired target color. After describing the security features, we will explain how the cellular ink-spreading enhanced Yule-Nielsen modified spectral Neugebauer model works and how it can be applied to create security features.

Key words Security features; Document authentication; Fluorescent ink; Color prediction model

基于印刷的视觉安全特征

HERSCH Roger D
(瑞士洛桑联邦理工学院，洛桑 1015，瑞士)

摘要 利用安全特性来确保纸币、支票、身份证件、证书、商业文件以及珍贵商品的真实性在当今社会是非常重要的。本研究简要描述了依赖于色彩预测模型的三个安全特性。色彩预测模型可以用于正向和逆向两种模式：正向模式中，通过已知的表面油墨网点覆盖率来预测一种颜色；逆向模式中，通过创建一个理想的目标颜色来计算表面油墨网点覆盖情况。随后，将介绍如何经过蜂窝油墨铺展增强效应的尤尔－尼尔森（Yule-Nielsen）来修正光谱聂格伯尔（Neugebauer）模型以及此模型如何创建安全特性。

关键词 安全特征；文件验证；隐形荧光油墨；颜色预测模型
中图分类号 TS801；TP309 **文献标识码** A **文章编号** 1674－5752(2014)06－60－05

0 Introduction

In the framework of today's globalization, it is important to be able to identify unambiguously any person at any possible place. Counterfeits of identity documents are widespread and create difficulties in many countries.

There is also a need for additional protection of banknotes and checks. With today's high-performance desktop tools, counterfeiters may scan and reproduce images with only a small degradation in quality. We therefore need protective features that are not reproducible with classical cyan, magenta, yellow and black inks.

Besides the identification of persons, it is also necessary to identify valuable goods. The pharmaceutical industry is specially concerned by this problem. Counterfeited drugs may be contaminated or contain the wrong ingredients and therefore be harmful to the people's health. Since the production of drugs is distributed over many different countries in different continents, there is a need for track and trace and authentication systems. In addition, retailers or possibly customers should be able to verify that a drug is authentic.

收稿日期：2014－09－13
项目来源：Swiss National Science Foundation (No. 200021－143501).

There is also a need to associate authentication features to commercial goods, in order to distinguish between originals and counterfeits. This applies to all kinds of goods, from luxury goods such as watches to components of machines and cars.

1 Document Security: Fundamental Aspects

Every security feature may be subject to forgery, given enough time and money. The goal of a security feature is to make counterfeiting a very difficult task. Therefore, in order to protect a given item, there is a need for several security features, possibly combined with one another. High security is obtained from security features that are individualized, i. e. the security itself contains a reference to the document or article that is to be secured, e. g. the name of the document holder or the product number of a luxury article. Individualized security elements can also be photographed by a smartphone, transferred to a Web server and remotely authenticated by that server.

2 Security Features Relying on a Special Substrate or on Custom Inks

Prints are characterized by a substrate and ink halftones printed on that substrate. Security features may rely on a special substrate, such as a fluorescent substrate or a metallic substrate. They may also rely on inks which differ from classical cyan, magenta, yellow and black inks. For example metallic inks show a specular effect, daylight fluorescent inks have a different reflectance when seen under a UV or a blue illuminant and invisible fluorescent inks can only be seen under UV light.

3 Security Features Relying on Spectral Prediction Models

The interaction of light, ink halftones and substrates can be modelled by spectral prediction models [1 - 2]. The talk presents three security features that all rely on such spectral prediction models. Note that each spectral prediction model, under a given illuminant, is also a color prediction model.

The first security feature enableshiding patterns under non-specular viewing conditions and revealing them under specular viewing conditions. This is achieved by having a first prediction model capable of predicting the colors printed with classical cyan, magenta and yellow (cmy) inks and a second model capable of predicting the colors obtained by printing with the silver ink and the classical cyan, magenta and yellow ($sc_s m_s y_s$) inks [3 - 4]. We assume that the image to be rendered is already color separated for the classical cmy inks. The first model predicts the color to be rendered at the current location within the print and the second model is asked to fit the surface coverages of the $sc_s m_s y_s$ inks in order to yield a color as close as possible to the color that is to be rendered at that location. Since the models are calibrated to work under non-specular viewing conditions, the patterns imaged with the $sc_s m_s y_s$ inks are completely hidden. They are revealed when the print is observed under specular viewing conditions.

The second security feature is based on completely invisible inks that have a fluorescent emission when exited under UV light [5]. We use invisible fluorescent inks that upon UV excitation emit in the red, yellow and blue wavelength ranges, respectively. We measure their emission spectra in the visible wavelength range. We obtain the printable fluorescent color gamut by using the spectral Neugebauer prediction model to predict all possible fluorescent colors that can be emitted under UV light, when varying the inks' surface coverages. This fluorescent gamut is then used for gamut mapping. The calibrated spectral Neugebauer prediction model also enables establishing the color separation tables. This results in a workflow enabling to print full color images that are invisible under daylight and visible under UV light.

The third security feature relies on daylight fluorescent inks, i. e. inks that absorb light in the visible wavelength range and reemit part of the absorbed energy at higher wavelengths. We use the magenta fluorescent ink and the yellow fluorescent ink. Both inks provide brighter and more chromatic colors, compared with classical magenta and yellow inks. Patterns to be hidden under normal daylight or under artificial light are printed with a combination of the classical and of the daylight fluorescent inks. Both the classical inks and combinations of classical and daylight fluorescent inks are each one characterized by a calibrated cellular Yule-Nielsen modified spectral Neugebauer model [6]. When a given color is to be printed and is located within the pattern that is to be hidden, the fluorescent ink color prediction model is asked to compute the ink surface coverages necessary to yield the desired color. This enables hiding the authentication patterns under normal light and revealing them under blue light or under UV light [7].

4 Spectral and Color Prediction Models

Both in classical color reproduction workflows and to implement various security features, it may be necessary to be able to predict the color of a print sample seen by a human being under specific illumination and observation conditions. Most color prediction models rely on the reflectances of the Neugebauer primaries, i. e. the reflectances of the fulltone inks alone, of the superpositions of fulltone inks and of the paper. In the simple spectral Neugebauer model, the predicted reflectance is a weighted sum of the reflectances of the Neugebauer primaries, where the weights are given by their surface coverages. In the case of independently printed layers of inks, the Demichel equations [8] enable computing the area coverages of the Neugebauer primaries, e. g. in the case of cyan, magenta and yellow inks, the areas a_w of white, a_c of cyan, a_m of magenta, a_y of yellow, a_r of red (yellow + magenta), a_g of green (yellow + cyan), a_b of blue (cyan + magenta) and a_k of chromatic black (cyan + magenta + yellow).

The more sophisticated Yule-Nielsen modified spectral Neugebauer model performs the weighted average of the reflectances in a power function space. In this widely used model, the spectral reflectance $R(\lambda)^{1/n}$ of a color halftone is predicted as a weighted sum of the reflectances $R_j(\lambda)^{1/n}$ of the primaries, where weight a_j is the area coverage of the j^{th} Neugebauer primary, $R_j(\lambda)$ is reflection spectrum and n the Yule-Nielsen value accounting for the lateral propagation of light, i. e. accounting for the optical dot gain:

$$R(\lambda)^{1/n} = \sum_j a_j R_j(\lambda)^{1/n} \tag{1}$$

The scalar value n that accounts for the lateral propagation of light in halftones is a function of the halftone dot frequency and of the halftone dot profile [9]. In general, n is between 1 and 100 or between -1 and -100 [10]. Its value is chosen so as to minimize the difference between measured and predicted reflection spectra on a limited set of halftone model calibration samples.

The Yule-Nielsen modified spectral Neugebauer model is further enhanced by performing a cellular sub-division of the ink surface coverage space into sub-domains. Each sub-domain, for example the subcube formed by ink coverages varying between 0 and 50% (Fig. 1), forms itself a Yule-Nielsen modified spectral Neugebauer model defined by 8 of the 27 primary reflectances.

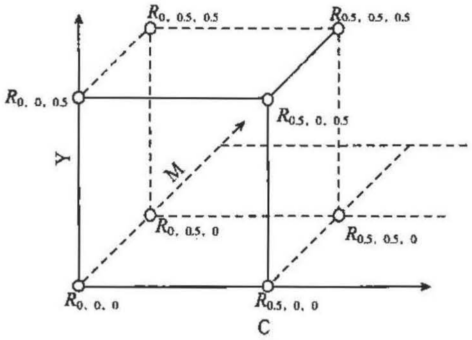

Fig. 1 Sub-domain with nominal surface coverages between 0 and 50%

图1 正常表面覆盖率为0~50%的子域

Within a sub-domain, the predicted reflectance is calculated by first normalizing the surface coverages c, m, y between the lowest (c_l, m_l, y_l) and the highest (c_h, m_h, y_h) surface coverages in the current sub-domain:

$$c' = \frac{c - c_l}{c_h - c_l} m' = \frac{m - m_l}{m_h - m_l} y' = \frac{y - y_l}{y_h - y_l} \tag{2}$$

Then with the Demichel equations, one calculates the area coverages of the "pseudo" Neugebauer primaries:

$$\begin{aligned} &a'_w = (1-c')(1-m')(1-y');\ a'_r = (1-c')m'y' \\ &a'_c = c'(1-m')(1-y');\ a'_g = c'(1-m')y' \\ &a'_m = (1-c')m'(1-y');\ a'_b = c'm'(1-y') \\ &a'_y = (1-c')(1-m')y';\ a'_k = c'm'y' \end{aligned} \tag{3}$$

The reflectances within a sub-domain are predicted as a function of the normalized area coverages a'_i of the "pseudo" Neugebauer primaries and the sub-domain vertex reflectances $R_i(l)$:

$$R(\lambda)^{pred} = \left[\sum_i a'_i \cdot R_i(\lambda)^{1/n}\right]^n \qquad (4)$$

In order to account for ink spreading, one further fits the effective normalized surface coverages of the inks at the center of each subcube by minimizing the squared distance between the measured and the predicted reflectance vectors. For example, for the sub-domain shown in Fig. 1, effective normalized surface coverages of the three inks are fitted by having the predicted reflectance as close as possible to the reflectance measured at nominal surface coverages of $c = 0.25$, $m = 0.25$ and $y = 0.25$. By linear interpolation, we obtain one ink spreading curve per ink and per sub-domain (Fig. 2).

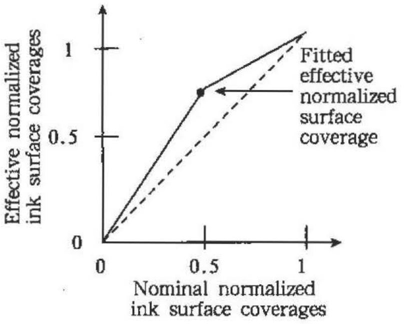

Fig. 2 One ink spreading curve per ink and per sub-domain
图2 每个子域每种墨水中的墨水扩散曲线

At reflectance prediction time, using the ink spreading curves, nominal normalized ink surface coverages are converted to effective normalized ink surface coverages which are then inserted into Eqs. (3) to obtain the effective area coverages of the "pseudo" Neugebauer primaries. These effective area coverages are then inserted into Eq. (4) to obtain the predicted reflectance.

Under a given illuminant, one may deduce from the reflectanceof a sample its CIE-XYZ tristimulus values accordingto the CIE 2° standard observer. One may then convert these tri-stimulus values to CIELAB [11]. These prediction models can be used in order to populate the ICC profiles for color reproduction, for example for the characterization of printers.

Thanks to optimization methods such as gradient descent, these prediction models can be used to obtainthe surface coverages yielding a desired printed color. This is especially useful for creating security features which are hidden under some viewing conditions and revealed under other viewing conditions.

5 Conclusions

Color prediction models are extremely useful for creating security features. There is one set of inks for creating the security foreground patterns and another set of inks for creating the background. Under a certain illumination such as daylight or under a certain viewing geometry, both sets of inks produce the same colors. Under a different illumination, such as blue light, or under a different viewing geometry, the two sets of inks produce very different colors and the hidden security patterns become apparent.

Thanks to well calibrated color prediction models, we can obtainthe exact ink surface coverages of a set of inks to be printed in order to obtain a certain color under a given illumination or for a given viewing geometry. Color prediction models also enable us to predict how far apart the color printed with one set of inks is from the color printed with another set of inks. Therefore, we can optimize the trade-off specifying how well we can hide the patterns under some illumination and viewing conditions and how well we can see them under other illumination and viewing conditions.

References

[1] R. Balasubramanian, Optimization of the Spectral Neugebauer Model for Printer Characterization [J]. Journal of Electronic Imaging, 1999, 181: 156-166.

[2] M. Hé bert, R. D. Hersch, Review of Spectral Reflectance Models for Halftone Prints: Principles, Calibration, and Prediction Accuracy [J]. Color Research and Application, Accepted for Publication.

[3] R. D. Hersch, F. Collaud, P. Emmel, Reproducing Color Images with Embedded Metallic Patterns [J]. Proc. SIGGRAPH ACM Trans. on Graphics, 2003, 22(3): 427-436.

[4] T. Bugnon, A. Maesani, R. D. Hersch, Enhancing the Specular Effect of Metallic Color Prints by Reducing the Use of Yellow Ink [J]. Journal of Imaging Science and Technology, 2011, 55(6): 060506, 9.

[5] R. D. Hersch, P. Donzé , S. Chosson, Color Images Visible under UV Light [J]. Proc. Siggraph 2007, ACM Trans. Graph. 2007, 26(3): 75, 9.

[6] R. Rossier, T. Bugnon, R. D. Hersch, Introducing Ink Spreading within the Cellular Yule-Nielsen Modified Neugebauer Model, Proc. IS&T/SID´s 18th Color Imaging Conference, 2010: 295 - 300.

[7] R. Rossier, R. D. Hersch, Hiding Patterns with Daylight Fluorescent Inks, Proc. IS&T/SID´s 19th Color Imaging Conference, 2011: 223 - 228.

[8] D. R. Wyble, R. S. Berns, “A Critical Review of Spectral Models Applied to Binary Color Printing,” Color research and application 25(1), 2000: 4 - 19.

[9] M. Hébert, R. D. Hersch, Analyzing Halftone Dot Blurring by Extended Spectral Prediction Models [J]. Journal of the Optical Society of America A, Vol. 27, 2010, 27: 6 - 12.

[10] A. Lewandowski, M. Ludl, G. Byrne, and G. Dorffner, Applying the Yule-Nielsen Equation with Negative *n* [J]. Journal of the Optical Society of America A, 2006, 23(8): 1827 - 1834.

[11] G. Sharma, Digital Color Imaging Handbook, Chapter 1, CRC Press, 2003: 30 - 38.

Main Author

HERSCH Roger D, he got the doctor degree. He is professor of computer science and head of the Peripheral Systems Laboratory at the Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland. His main research focuses on novel imaging techniques for color reproduction and document security (spectral color prediction models, metallic images, fluorescent color images and moiré imaging).

HERSCH Roger D，博士，计算机科学专业教授，外围系统实验室主任；主要研究方向为新型彩色复制图像技术和防伪技术，包括光谱颜色预测模型、金属色图像、荧光彩色图像和摩尔纹图像。

E-mail: RD. Hersch@ epfl. ch

(上接第44页)

[6] 王彬宇. 多墨打印系统的Neugebauer光谱特征化模型研究[D]. 浙江：浙江大学，2012.

WANG Bin-yu. Study of Spectral-Based Neugebauer Characterization Model for a Multi-Ink Printer [D]. Hangzhou: Zhejiang University, 2012

[7] KRISTINA Marijanovic. Spectral Print Reproduction-Modeling and Feasibility [D]. Norway: Gjøvik University College, 2012

[8] MEKIDES Assefa. Kubelka Munk Theory for Efficient Spectral Printer Modeling [D]. Norway: Gjøvik University College, 2010

[9] JEREMIE Gerhardt, JON Yngve Hardeberg. Simple Comparison of Spectral Color Reproduction Workflows [J]. SCIA, 2009: 550 - 559

[10] JEREMIE Gerhardt, JON Yngve Hardeberg. Spectral Color Reproduction Minimizing Spectral and Perceptual Color Differences [J]. Color Research & Application, 2008, 33: 494 - 504.

主要作者

陈琳琳（1989年－），硕士研究生；主要研究方向为色彩再现与印刷图文处理。

CHEN Lin-lin, born in 1989. He is a master student and his research interests include color reproduction and printing graphic processing.

E-mail: chen_lin_lin_yi@ 163. com

陈广学（1963年－），工学博士，教授，博士生导师；主要研究方向为数字图像信息处理、数字加网与高保真印刷，数字印刷与电子出版等。

Prof. CHEN Guang-xue, born in 1963. He got the doctor degree and now is the Ph. D. supervisor. His main research interests include color image processing, digital halftoning and Hi-Fi printing, digital printing technique.

E-mail: chengx@ scut. edu. cn