Analysis of Adaptation Problems of Scanning and Printing Devices for Color Reproduction

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Abstract

In this paper, the adaptation problems of color scanning and printing devices are considered for achieving a good performance of color reproduction. Several essential factors that cause these two devices with time varying parameters are reviewed. It is then shown that, based on the plant inverse scheme, the color print-out will be close to the scanned image within the gamut of printing system, if a color corrector can work as a model-free estimator and the system functions of scanning and printing devices are invertable.

I. Introduction

In color management technology, the process of device-independent color reproduction has given considerable emphasis on how the color can be well-reproduced from scanning and printing devices. However, it can hardly perform the automatic adaptation for color reproduction. In Kang's paper[1], it has shown that the calibration of a color scanning device is material-dependent, that is, there doesn't exist a unified transfer matrix regarding various input document materials. On the other hand, while the different batches of the same inking materials are used in the machine, the nonlinear characteristics of a color printing device is also influenced. Therefore, for color reproduction, the consideration of adaptation is very important to avoid the color error propagation between these two devices.[2]

A mathematical approach for analyzing the adaptation problem is proposed in this paper. In a systematic way, it is assumed that the characteristics of scanning and print- ing are nonlinear functions with time varying paramet- ers. While proper self-test color patches are selected, the device-dependent color space can be truly characterized. In practice, the adaptation problem is usually based on the self-tuning scheme, that is, after driving these test patches to the color printing device, the composite characteristics of these two devices can be obtained by feeding back the print-out of these test patches to the scanning device.[3] In this paper, two theorems are presented to show that if the performance of the color corrector, which is placed between these two devices, is good enough and if the system functions of scanning and printing devices with time dependence are invertable, then the color print-out will be close to the scanned original within the gamut of printing system.

II. Color Scanning and Printing Systems with Time Varying Parameters

There are many essential factors that will cause the parameters of scanning systems to become time varying. For instance, different input document materials and decay of the strength of illumination are some of the main factors. Similarly, the parameters of printing systems are also influenced by using different batches of inking materials, various halftoning techniques, etc. Hence, these situa- tions can be covered by two cases. In one case, parameters change abruptly but seldom; while in the other case the parameters are varying slowly. A scanner-printer reproduction system with color correction can be illustrated as in Fig. 1.

Consider a general scanning system described by

$$\mathbf{s_t} = S(t, \mathbf{x}),\ t \geq 0 \tag{1}$$

where S: $R \times R^3 \rightarrow R^3$; $\mathbf{x} \in D_i$, $\mathbf{x}$: a device-dependent color coordinate, D_i : the hyperspace of input scanning color space, and $D_i \subset R^3$; $s_t \in D_s$, the output scanning color coordinate, D_s: the gamut of scanning system, and $D_s \subset R^3$. If we now consider the system

$$\mathbf{s}_l = S(\ l,\ \mathbf{x}),\ l \geq 0 \tag{2}$$

where l is a particular nonnegative number, then we can think of (2) as a particular case of the system (1) "frozen" at time l. Similarly, a general printing system can be described as

$$\mathbf{p_t} = P(t, \mathbf{y}),\ t \geq 0 \tag{3}$$

where P: $R \times R^3 \rightarrow R^3$; $\mathbf{y} \in D_n$, $\mathbf{y}$: a device-dependent color coordinate, D_n: the hyperspace of input printing color space, and $D_n \subset R^3$; $\mathbf{p}_t \in D_p$, $\mathbf{p}_t$: the output printing, color coordinate, Dp: the gamut of printing system, and $D_p \subset R^3$. Then for any $r \geq 0$, the printing system

$$\mathbf{p_r} = P(r, \mathbf{y}),\ r \geq 0 \tag{4}$$

can be thought as the system (3) frozen at time r.

By the plant inverse approach[3], as shown in Fig. 2, the composite characteristics of scanning and printing systems, $\mathbf{s_l} \circ \mathbf{p_r}$, can be obtained. In Sec. III, the adaptation problem of a scanner-printer system will be discussed.

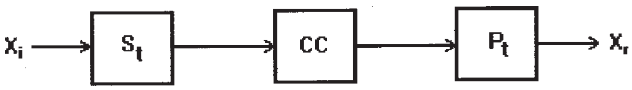

Figure 1. Scanner-Printer reproduction system with color correction

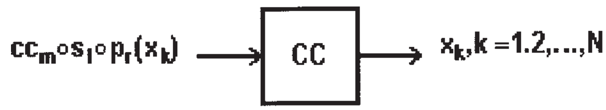

Figure 3. Learning process of color corrector

III. Adaptation Problem for Color Reproduction

The plant inverse scheme proposed in[3] consists of the characterization process and the learning process, as shown in Fig. 2 and Fig. 3, respectively. Two theorems of the adaptation problem for this scheme can be obtained as follows,

Theorem 1:

If $cc_m \circ s_l \circ p_r(X_k), \rightarrow X_k$ as $m \rightarrow \infty$, pointwise in R^3, for $k = 1, 2, \ldots, N$, and $\forall X_k \in D_s$, then $cc_m \rightarrow (s_l \circ p_r)^{-1}$ or $cc_m \rightarrow p_r^{-1} \circ sl^{-1}$, in L^2, as $m \rightarrow \infty$, where $s_l \circ p$, s_l and p_r are invertable.

Proof:

According to Cauchy-Schwarz Inequality,

$$\left\| cc_m - (s_l \circ p_r)^{-1} \right\|_2 \le \left\| cc_m - s_l \circ p_r - I \right\|_2 \cdot \left\| (s_l \circ p_r)^{-1} \right\|_2,$$

Since $\left\| (s_l \circ p_r)^{-1} \right\|_2$ is bounded and

$\left\| cc_m \circ s_l \circ p_r - I \right\|_2 < \varepsilon$, as $m \rightarrow \infty$, then

$$\left\| \boldsymbol{cc_m} - \boldsymbol{s_l} \circ \boldsymbol{p_r}^{-1} \right\|_2 < \varepsilon, \text{ as } m \rightarrow \infty.$$

That is $\boldsymbol{cc_m} \rightarrow (\boldsymbol{s_l} \circ \boldsymbol{p_r})^{-1}$, as $m \rightarrow \infty$, in L^2.

Moreover, $cc_m \rightarrow p_r^{-1}\, s_l^{-1}$, as $m \rightarrow \infty$, in L^2, if s_l and P_r are invertable.

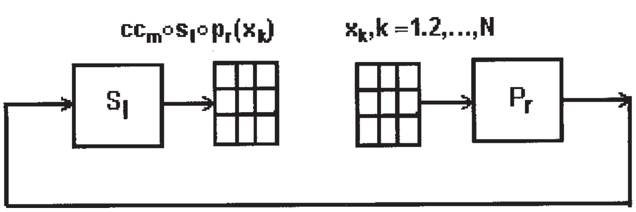

Figure 2. Characterization process for scanning and printing systems

Theorem 2:

Consider the case $p_r \circ cc_m \circ s_l\,(x_i) = x_r$ as in Fig. 1, that is, a scanner-printer reproduction with color correction, If $cc_m \rightarrow p_r^{-1} \circ s_l^{-1}$ as $m \rightarrow \infty$ in L^2, then $x_r \rightarrow x_i$ in $D_p \subset R^3$, where x_r, $x_i \in D_p$ and $D_p \subset D_s$.

Proof:

Notice that

$$\left\| p_r \circ cc_m \circ s_l - I \right\|_2 = \left\| p_r \cdot (cc_m - p_r^{-1} \circ s_l^{-1}) \cdot s_l \right\|_2, \text{so}$$

$$\left\| p_r \circ cc_m \circ s_l - I \right\|_2 \le \left\| p_r \right\|_2 \cdot \left\| cc_m - p_r^{-1} \circ s_l^{-1} \right\|_2 \cdot \left\| s_l \right\|_2,$$

Since $\left\| \boldsymbol{p_r} \right\|_2$ and $\left\| \boldsymbol{s_l} \right\|_2$ are bounded, and $cc_m \rightarrow Pr^{-1} \circ sl^{-1}$ as $m \rightarrow \infty$ in L^2, by assumption, we have

$$\left\| p_r \circ cc_m \circ s_l - I \right\|_2 < \varepsilon, \text{ as } m \rightarrow \infty.$$

That is

$x_r \rightarrow x_i$ in $D_p \subset R^3$, where x_r, $x_i \in D_p$ and $D_p \subset D_s$.

IV. Conclusions

The adaptation problem for color reproduction has been presented by a rigorous mathematical approach. It is stated that the color print-out will get close to the scanned origi-nal within the gamut of printing system, if the color corrector can be regarded as a model-free estimator and those system functions of scanning and printing devices with time dependence are invertable.

References

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