

Inverse of Transmission Characteristics of Printing Ink Layers by Using an Adaptive Inverse Filter for Illuminants

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Abstract

In this paper, an ill condition problem which estimate a transmission characteristics under the assumption that only the output characteristics can be observed. In the inverse problem, the physical characteristics of a printing ink (colorant) layer correspond to the transmission characteristics, an illuminant corresponds to the input and the reproduced color corresponds to the output. For a solution of the inverse problem, an adaptive inverse filter for illuminants is employed to remove the characteristics of illuminants. And an inverse solution method to estimate the transmission characteristics is applied after removing the characteristics of an illuminant. Simulation results have shown the efficiency of the method.

1. Introduction

In these days, researches have been carried out about system description of transmission characteristics of a colorant layer.[1,2] These models are generalization of the Kubelka-Munk model. In this paper, with a system description about a colorant layer, the inverse problem of transmission characteristics is solved.

The problem is an ill condition problem which estimate a transmission characteristics under the assumption that only the output characteristics can be observed. In the inverse problem, the physical characteristics of a colorant layer correspond to the transmission characteristics, an illuminant corresponds to the input and the reproduced color corresponds to the output.

For a solution of the inverse problem, an adaptive inverse filter for illuminants is employed. In general, spectral characteristics of white illuminants have not stand out features in a specific color spectral range and can be approximated by a low order linear system, except for special cases. In the proposed method, the spectral characteristics of an illuminant is estimated and removed by using an adaptive inverse filter of low order linear system. The filter makes the input spectral characteristics flat. After the pre-processing, the characteristics correspond to the colorant layer transmission. The characteristics can be converted to the transmission characteristics of reflection parameters at colorant layer bounds based on a linear system model which approximates non-linear transmission in short intervals in a spectral range. The linear system model called forward-backward wave model[3)] in speech science and engineering has been applied.

In the section 2, the model proposed in the paper is described. In the section 3, simulations have been performed to confirm the efficiency of the proposed method. Finally, in the section 4, conclusions are provided.

2. System Description and Inverse of the System

2.1. System Description

In the problem, the physical characteristics of a colorant layer correspond to the transmission characteristics, an illuminant corresponds to the input and the reproduced color corresponds to the output as shown in Figure 1. Though models in which an colorant layer is on a paper is practically important, but these models will be discussed in another paper.

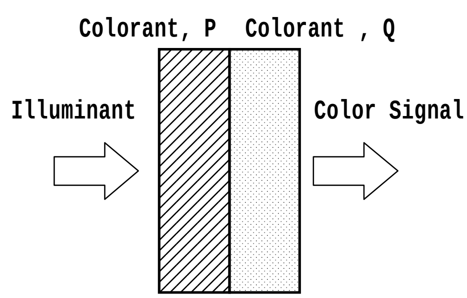

Figure 1. Colorant layer

Fig. 2 shows the transfer system model, and its inverse model. In Fig. 2, the input to the illuminant model is a white noise, and the output of the colorant model is the reproduced color. To the reproduced color, the inverse model of the illuminant is applied and the inverse model of colorant is estimated as an inverse solution.

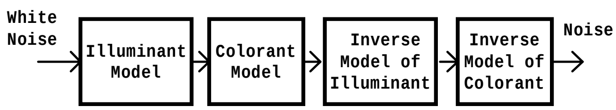

Figure 2. System flow

The colorant model is described based on a linear system model which approximates non-linear transmission in short intervals in a spectral range. For each linear system, the forward-backward wave model proposed in speech synthesis and analysis field is employed. And its inverse solution method provides the solution of the inverse problem. In the wave model, wave transfer in colorants is described as follows:

$$f_{n+1}(t) = (1-\gamma_n)Df_n(t) + \gamma_n Db_{n+1}(t)$$
$$b_n(t) = Db_{n+1}(t) - \gamma_n\left[Df_n(t) - Db_{n+1}(t)\right] \quad (1)$$

where,
f_n : forward wave in the n-th layer,
b_n : backward wave in the n-th layer,
r_n : reflectance coefficient between the n-th layer and the (n+1)-th layer,
D : Δt time delay factor.

Equation (1) corresponds to a differential system of one ordered. In the section, it is assumed that the depth for each colorant is the same, and in the time of Δt, waves travel the depth length. The meaning of eq.(1) is explained by using Fig. 3.

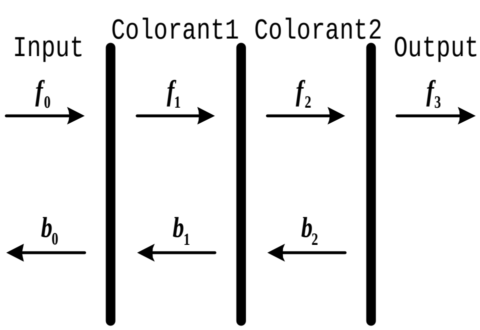

Figure 3. Wave model

The segment including the boundary between the colorant 1 and the colorant 2 is considered at a time *t*. The forward wave *f1* traveling to the right in the colorant 1 is splited in the *f2* wave in the colorant 2 and in the b1 wave in the colorant 1 depending on *r1* value, at the time *(t+*Δ*t)*. The backward wave b2 traveling to the left in the colorant 2 is splited in the *b1* wave and in the *f2* wave.

In the section, two colorant case is explained. All possible cases can be modeled in the same way.

2.2. Inverse of the Colorant Model

Inverse of the colorant model is derived by the deformation of eq.(1), as follows :

$$Df_n(t) = Db_{n+1}(t) + q_n\left[f_{n+1}(t) - Db_{n+1}(t)\right]$$
$$b_n(t) = f_{n+1}(t) - q_n\left[f_{n+1}(t) - Db_{n+1}(t)\right]$$
$$q_n = 1/(1-\gamma_n)$$
$$(2)$$

In eq.(2), the forward wave and the backward wave in the n-th layer are calculated by the forward wave and the backward wave in the (n+1)-th layer. By using the relation of eq.(2), the inverse model is estimated traveling from the output signal to the input signal. The reflectance coefficients between the n-th layer and the (n+1)-th layer are unknown parameters which should be estimated. Under the assumption that the spectrum of an input signal is flat (white), the reflection coefficients can be evaluated as follows :

$$\gamma_n = \frac{(f_{n+1} \cdot Db_{n+1})}{\|Db_{n+1}\|^2} \quad (3)$$

where,
( ) : inner product about time.

Eq. (3) is derived by the inner product of the Db_{n+1} and the both sides of the first equation of eq. (2). On the derivation, the relationship $(Db_{n+1} \bullet Df_n)=0$ is used. The relationship consists under the assumption that the spectrum of an input signal is flat[3].

In eq.(1), eq(2), attenuation is not considered. Let assume ξ to be attenuation coefficient in the n-th colorant, and ξf_n , ξDb_n are used in eq.(1), instead of f_n , Db_n . In eq.(2), in the inverse traveling, inverse compensation of ξ is performed.

Under the assumption of perfect radiation (reverse of perfect reflectance), the reflectance coefficient between the colorant layer *k* which look out on the outer space and the outer space equals to -1. To preserve the boudary conditon, ξ_k is included in the output signal, on behalf of including in f_k , Db_k .

The reflectance coefficients can be mutually transformed with the AR (Auto regressive) linear model parameters. The AR models are described in both frequency domain and time domain. In the case that output color signals are observed in a frequency domain, spectral data is approximated by the AR model, and the AR parameters can be converted to reflection coefficients.

2.3. Adaptive Inverse Filter for Illuminants

For the estimation of reflection coefficients, input signals should be white as described in section 2.2. The inverse filter for illuminants eliminates the characteristics of illuminants and the input signals becomes white (flat spectrum) equivalently. In general, spectral characteristics of white illuminants have not stand out features in a short interval of a spectral range, and can be approximated by a low order linear system. In the paper, a one ordered linear system is employed.

$$i(t)=c\,D\,i(t) + noise(t) \qquad (4)$$

where,

noise : input noise signal,
i : illuminant signal,
c : filter coefficient.

The inverse filter for illuminants is as follows :

$$O'(t)=o(t) - c\,D\,o(t) \qquad (5)$$

where,

O : output color signal,
O' : filtered color signal.

Under the assumption that only an output signal can be observed, the fiter coefficient is estimated against the output color signal by the least squared error prediction, adaptively.

2.4. Colorant Model Variation

In the section 2.2, it is assumed for convenience that the depth for each colorant is the same, and in the section the restriction is removed. By subdividing colorants depth virtually, a colorant layer can be seem to be a layer composed by the same depth colorants. Fig.4 shows an example. The dashed line is virtual boundary. On the virtual boundary, reflectance coefficient is 0, and there are no modifications to the waves.

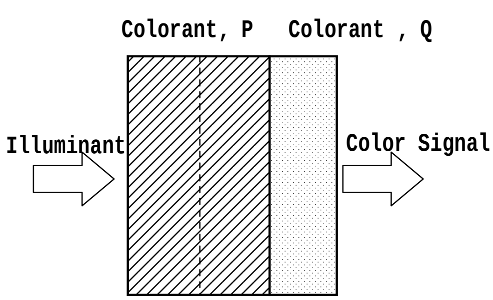

Figure 4. Colorant layer

On the boundary conditions described above, the inverse problem can be solved in the section 2.2 framework.

3. Simulations

Simulations have been performed to confirm the efficiency of the proposed model.

The colorant layer model shown in Fig.1, Fig.4 are used. The wavelength range 380nm~760nm was divided into eight intervals. The attenuation coefficients are known a priori, and ξ_1=0.8, ξ_2=0.6. A white noise is employed as the input of the illumination model. The illuminant filter coefficient *C* is 0.5.

Table 1 and Table 2 show simulation results for the model of Fig. 1. In the simulations of Table 1, the exact inverse illuminant model is applied. In the results, the characteristics of the illuminant are removed exactly. In the simulations of Table 2, the parameter of the inverse illuminant model is estimated. The estimation errors for reflectance coefficients are increased because of the estimation error for the illuminant filter coefficient. The error in Table 1 are 1.0~7.2%, and the average is 3.2%. The error in Table.2 are 1.1%~12.8%, and the average is 6.6%.

Table 3 and Table 4 show simulation results for the model of Fig. 4. In the simulation of Table 3, the exact inverse illuminant model is applied. In the simulation of Table 4, the parameter of the inverse illuminant model is estimated. The error in Table 3 are 0.3%~4.9%, and the average is 1.8%. The error in Table 4 are 0.6%~9.5%, and the average is 4.2%.

Though the inverse solution method has been established in speech analysis field, these results show the efficiency applied to the inverse problem.

Table 1. Simulation results

r 0 *r* 1	(estimated) *r* 0	estimated) *r*1
0.5 0.5	0.488824	0.505430
0.7 0.2	0.691274	0.208513
0.3 0.1	0.290294	0.107242

Table 2. Simulation results

r 0 *r* 1	(estimated) *r* 0	(estimated) *r*1
0.5 0.5	0.452715	0.504833
0.7 0.2	0.691337	0.235789
0.3 0.1	0.290982	0.111430

Table 3. Simulation results

r 0	*r* 1	*r* 2 (estimated)*r* 0	(estimated) *r*2
0.5	0 0.5	0.507603	0.501910
0.7	0 0.2	0.706379	0.203015
0.3	0 0.1	0.304272	0.104914

Table 4. Simulation results

r 0	*r* 1	*r* 2 (estimated)*r* 0	(estimated) *r*2
0.5	0 0.5	0.496617	0.547415
0.7	0 0.2	0.706291	0.212459
0.3	0 0.1	0.304350	0.106256

4. Conclusions

In this paper, an ill condition problem which estimate a transmission characteristics under the assumption that only the output characteristics can be observed. In the inverse problem, the physical characteristics of a colorant layer correspond to the transmission characteristics, an illuminant corresponds to the input and the reproduced color corresponds to the output. For a solution of the inverse problem, an adaptive inverse filter for illuminants is employed to remove the characteristics of illuminants. And an inverse solution method to estimate the transmission characteristics has been applied after removing the characteristics of an illuminant.

Simulations have been performed to confirm the efficiency of the proposed method. Though the inverse solution method has been established in speech analysis field, these results have shown the efficiency applied to the inverse problem.

It is difficult to measure reflectance coefficients directly. So the evaluation of the method by using real data is difficult in the same as in speech analysis field. The only way of the evaluation is measuring spectral distance between the model and real data, and hereafter, we will evaluate in this policy.

References

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Biography

Dr. Matsushiro received his BE degree, ME degree and Ph.D degree from the University of Electro-Communications, Tokyo, Japan, in 1980, 1982, and 1996, respectively. He is now a visiting scientist in Rochester Institute of Technology, New York, USA. He is the manager of the Research Laboratory, Oki Data Corporation, Japan. His research interest lies in data compression, color image processing, and 3D image processing.