A Spectral Imaging Method for Classifying Fluorescent Scene Illuminant

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ABSTRACT

This paper proposes a method for classifying fluorescent scene illuminant by using a spectral camera system with narrow band filtration. We use neither the low-dimensional linear model nor the color temperature. We note that wavelengths of the line spectra are inherent to fluorescent material of the light source, and the number of fluorescent materials is limited. Therefore it is possible to infer the material type of fluorescent light source by knowing the wavelength positions of spikes on the observed illuminant spectrum. The basic procedure of illuminant classification is to classify the illuminants into three groups based on the peak wavelength positions. Algorithms are developed for peak detection using the second derivative spectrum. Finally, the feasibility of the proposed method is demonstrated in an experiment.

1. INTRODUCTION

We discuss illuminant classification for inferring scene illumination with spiky spectrum. Most previous studies on the illuminant estimation problem supposed that the scene illumination has a continuous spectral-power distribution[1]. The illuminant spectrum is described using the low-dimensional linear model. However the spectral distribution of a fluorescent lamp shows strong spectral lines together with a weaker continuous portion of the spectrum. The illuminant spectra with spikes cannot be represented using the linear model with smooth basis functions. We previously presented the sensor correlation algorithm for classifying scene illuminations by color temperature of the blackbody radiators[2]. It was shown that the illuminant gamut of a fluorescent source differ from the illuminant gamut of the blackbody radiator with the same correlated color temperature[3].

In this paper we propose a method for classifying fluorescent scene illuminant by using a spectral camera system with narrow band filtration. We use neither the low-dimensional linear model nor the color temperature. We analyze illuminant spectra with spikes in a direct way. The spectral shape is decomposed into two portions of spikes and continuum, which correspond, respectively, to the bright line spectra and to the background continuous spectrum. We note that wavelengths of the line spectra are inherent to fluorescent material of the light source, and the number of fluorescent materials is limited. Therefore it is possible to infer the material type of fluorescent light source by knowing the wavelength positions of spikes on the observed illuminant spectrum. We consider a procedure for classifying scene illuminants based on the peak wavelength positions. We show that most fluorescent illuminant spectra are classified into three groups.

2. SPECTRAL CAMERA SYSTEM

Figure 1 shows a camera system for spectral imaging system using a liquid-crystal tunable (LCT) filter, a monochrome CCD camera, and a personal computer. The LCT filter operates over the range [400-700 nm], and the bandwidths are about 20 nm. The camera is a scientific camera with a cooling system to reduce noise. The bit depth of the image is 12 bits. We sample the visible wavelength range [400-700 nm] at intervals of 5 nm and acquire the monochrome images at 61 wavelengths. Moreover we acquire additional images at eight wavelengths of 404, 436, 488, 544, 580, 588, 612, and 656 nm that correspond to bright line spectra of main fluorescent lamps. Figure 2 shows the overall spectral-sensitivity functions, which are determined as a combination of the spectral-sensitivity functions of the monochrome camera and the spectral transmittances of the LCT filter. The bold curves in Figure 2 represent the additional sensor responses. Therefore, the spectral image consisting of a set of 69 monochrome images is acquired for one shot of a natural scene.

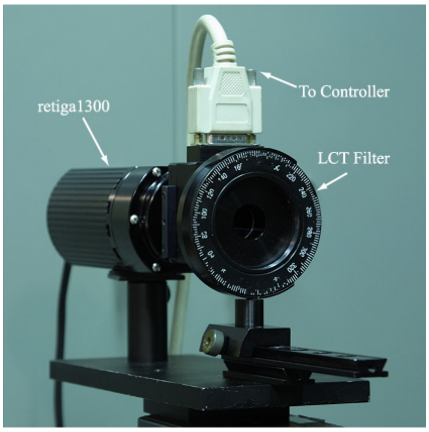


Figure 1: Spectral camera system.

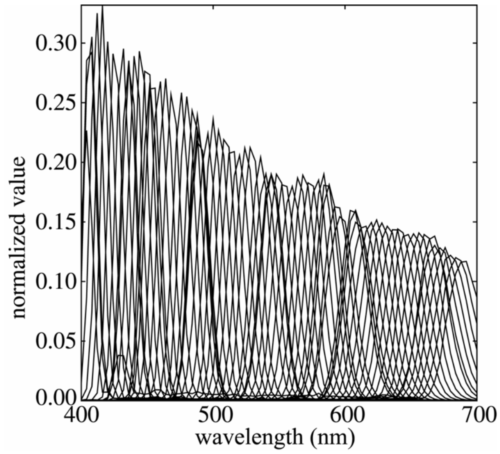


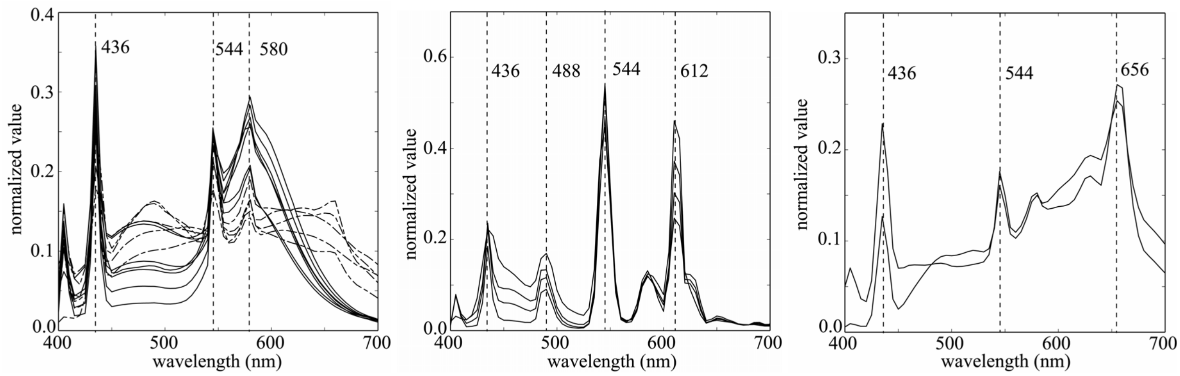
Figure 2: Overall spectral-sensitivity functions.

3. ILLUMINANT FEATURES AND CLASSIFICATION

The CIE[4] defines a set of illuminants representing typical fluorescent lamps that consists of twelve light sources, F1, F2, …, F12, including daylight fluorescence, cool white fluorescence, and three narrow-band fluorescence. In addition, we have collected six real fluorescent lamps. These fluorescent lamps are White W/M/36, Museum (daylight), Museum (bulb), Test Color D65, Mellow 5D, and Meat Display. Our database of fluorescent light sources consists of 18 light sources.

The spectral curve is divided into several peak areas and a background continuum. A set of the peak wavelengths provides us a key to identifying the unknown fluorescent light source when we observe scene illumination. We have analyzed sharp and big peaks. It is found that all the fluorescent spectral curves can be classified roughly into three groups as shown in Figure 3. The first group that we call the "Standard" type has the main peaks at 436, 544, and 580 nm, which includes CIE-F1, …, CIE-F9, White W/M/36, Museum (daylight), and Test Color D65. The second group called the "Three narrow-band" type has the main peaks at 436, 488, 544, and 612 nm, which includes CIE-F10, CIE-F11, CIE-F12, and Mellow 5D. The third group called the "Incandescent" type has the main peaks at 436, 544, and 656 nm. This group includes Museum (bulb) and Meet display.

The large set of the Standard group is furthermore analyzed. Note the shape of the background continua. Some spectral power distributions are flatter and have a wider range in the visible spectrum than the others. This "Broad band" group can be segregated based on a difference in shape of the background continuum around 620 nm. If the continuous spectrum is slant in the wavelength region, the fluorescent spectrum is called the Standard (Type A). If the spectrum is flat in the region, it is called the Broad band (Type B). The broken curves and bold ones in Figure 3 (a) represent, respectively, Type A and Type B.



(a) Standard type (b) Three broad-band type (c) Incandescent type

Figure 3: Classifications of fluorescent spectra into three groups.

4. CLASSIFICATION ALGORITHMS

4.1 Estimation of spectral radiance

Let the wavelength bands of the filter be *f* bands of $\lambda_1, \lambda_2, \ldots, \lambda_f$. If each band is narrow, then the camera outputs $\rho_k(x)$ at spatial location *x* can be decribeded by the equations

$$\rho_k(x) = \int_{380}^{720} Y(\lambda, x) R_k(\lambda) d\lambda = Y(\lambda_k, x) \int_{380}^{720} R_k(\lambda) d\lambda, \qquad (k = 1, 2, \ldots, f) \quad (1)$$

where $Y(\lambda, x)$ is the spectral radiance at the location *x* and $R_k(\lambda)$ is the spectral sensitivity function of the *k*-th channel. Under the narrow band assumption, the spctral radiance is estimated in the form

$$Y(\lambda_k, x) = \rho_k(x) \Big/ \int_{380}^{720} R_k(\lambda) d\lambda. \qquad (2)$$

For the purpose of illuminant estimation, we use the gray world assumption. It assumes that the average of surface reflectances over the entire scene is gray. Therefore the illuminant spectra is estimated as the average spectral radiance $\overline{Y}(\lambda_k)$ over the entire location *x*.

4.2 Detection of spike peaks

The fluorescent peaks are detected using the average spectral radiance $\overline{Y}(\lambda_k)$. However this peak detection is not always stable. We have performed a simulation using the Macbeth Color Checker and the Mellow 5D as a light source. It is supposed that the real image contains noises. In order to simulate the statistical noises, normal random numbers with means 0 and variances 1 were generated, and added to the computed camera outputs.

Figure 4 shows the average spectral outputs $\overline{Y}(\lambda_k)$ (k=1, 2, …, 69). The broken curve in the figure shows the real spectral curve of Mellow 5D, which was measured directly by a spectro-radiometer and a standard white reference. A comparison between two curves suggests that the average curve of the spectral camera outputs has no sharp peaks, so that the peak positions do not exactly correspond to the wavelengths of the fluorescent peaks.

We take the derivative of the camera output spectra for detecting "slow" changes on the spectral curves. The second derivative called the Laplacian calculates the divergence of the gradient of a spectral curve. We define the operation as

$$X''(\lambda_k) = -(X'(\lambda_{k+1}) - X'(\lambda_{k-1}))/(\lambda_{k+1} - \lambda_{k-1}). \qquad (k=1, 2, .., 69) \qquad (3)$$

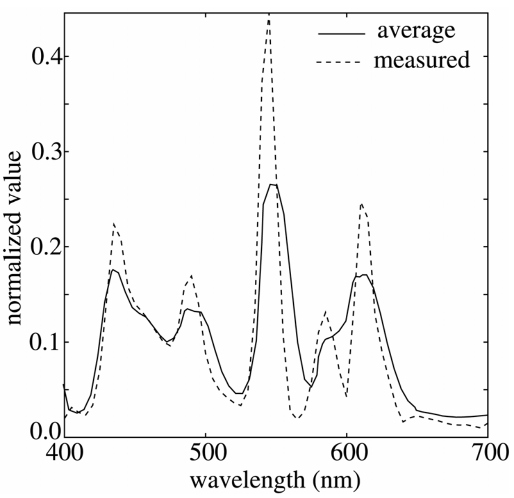


Figure 4: Average outputs and direct measurement.

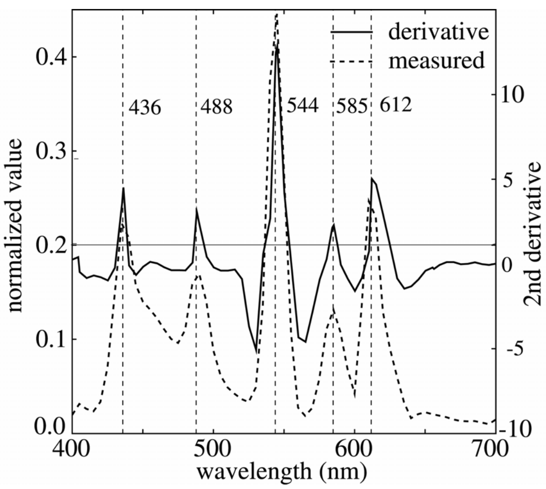


Figure 5: Average of the second derivative spectra.

This Laplacian operation is effective for peak detection. We take the second derivative spectra for all camera outputs. Figure 5 shows the average curve of the second derivatives. Sharp peaks are clearly generated, and the respective peak positions are coincident with the original fluorescent wavelengths on the broken curve in Figure 5. Therefore, the complicated problem of finding spike peaks on the estimated illuminant spectrum can be reduced to the problem of detecting peaks of the second derivative spectrum.

5. EXPERIMENTAL RESULTS

We have evaluated the proposed classification method for spectral images acquired under the six real fluorescent lamps. The objects are dolls and toys, which are made of plastics and paint materials. Figure 6 shows the scene under the Museum (bulb) lamp. We take the average of all pixel values for each spectral image at 69 channels. A comparison of the average spectral outputs with the real illuminant spectrum suggests that some fluorescent peaks do not appear clearly on the average spectral curve. Moreover, we take the second derivative for all the pixels. Figure 7 shows the average curve of the second derivatives. We can detect three main peaks at 436, 544, and 656 nm. According to the classification rule, this illumination is correctly classified into the incandescent type.

Figure 6: Object scene under Museum (bulb) lamp.

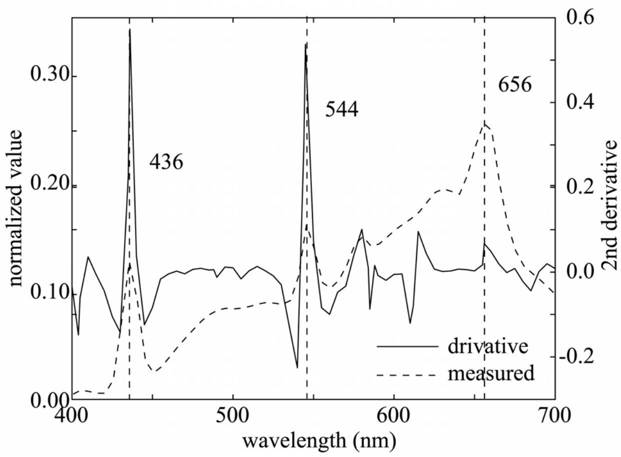


Figure 7: Average curve of the second derivatives.

6. CONCLUSION

We have described a method for estimating fluorescent scene illumination by using a spectral imaging system. The system was composed of a LCT filter, a monochrome CCD camera, and a personal computer. We used neither the linear model nor the color temperature for identifying a fluorescent lamp. We used the wavelengths of spike peaks on the illuminant spectrum. A procedure was proposed for classifying scene illuminants into three groups. A peak detection algorithm was developed using the second derivative spectrum for the classification. Finally, an experiment was executed using real fluorescent lamps and different object materials for demonstrating the feasibility of the proposed method.

References

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