High-fidelity color reproduction using hybrid-resolution spectral imaging

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***Abstract*— We introduce hybrid-resolution spectral imaging system for compact spectral video acquisition system. In this system, low-resolution spectral image and high-resolution RGB image are simultaneously captured and then high-resolution spectral image is generated. The system can capture spectral video in 3fps and displays reproduced color image under arbitrary illuminant.**

***Keywords*—color reproductiont; hybrid-resolution spectral imaging; spectral video; real time**

I. Introduction

Spectral imaging is receiving increased attention in various fields such as remote sensing, machine vision, biomedical imaging, forensics, digital archival of artworks and cultural heritages, and high-fidelity color reproduction. In the color reproduction applications, the spectral characteristics of materials enables to faithfully reproduce the color of the original object under different illuminant. However the input of spectral images requires spectral or spatial scanning or a number of sensors, and it is difficult to capture spectral video by a compact camera system. In addition, the light energy captured by a single pixel is reduced if the number of spectral channels is large, and it is challenging to obtain the image with high signal to noise ratio (SNR). In order to solve this problem, we have proposed a technique called hybrid-resolution spectral imaging [1-2], which efficiently acquires high-resolution spectral images in one-shot capturing. This system is composed of compact devices: a high-resolution RGB camera and a low-resolution spectral sensor (LRSS) [2]. In this paper, we introduce the concept, the spectral reconstruction methods, and the experimental results of the hybrid-resolution spectral imaging.

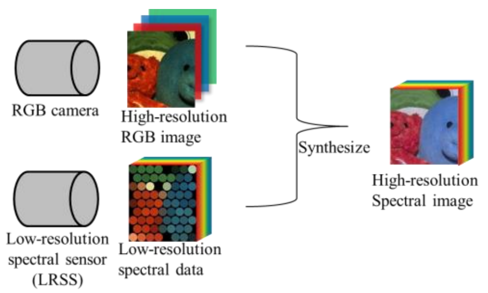

Fig. 1. The concept of hybrid-resolution spectral imaging system

II. Hybrid-Resolution Spectral Imaging

Fig. 1 shows the concept of a hybrid-resolution spectral imaging system. The RGB camera captures a 3-channel image with high spatial resolution, whereas the spectral resolution is high and spatial resolution is low in the data taken by the LRSS. Then those data are combined to derive a spectral image with high spatial and spectral resolution. For this purpose, we have developed image reconstruction methods as described in the next section. Even though the spatial resolution is low, the spectral data obtained by LRSS is beneficial for improving the accuracy of spectral reconstruction at each pixel of the high-resolution spectral image. Since the pixels size in LRSS is relatively large, more light energy can be captured at each pixel of spectral image, and high SNR can be achieved in the spectral image. Figs. 2 show the photographs of the prototype spectral video system. The RGB camera and the LRSS use different lenses respectively, where it is possible to combine the LRSS with an arbitrary high-resolution RGB camera.

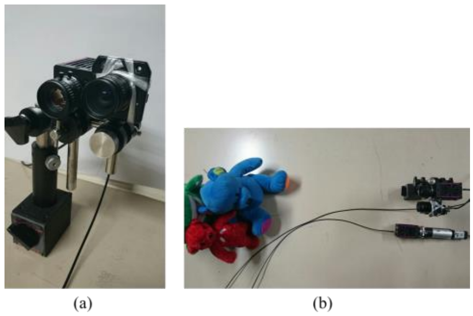

Fig. 2. Photographs of (a) the camera head of the hybrid-resolution spectral imaging system, and (b) the top view of the image capturing geometry.

III. Spectral Reconstruction Methods

Several methods have been proposed for reconstructing spectral images for hybrid-resolution spectral imaging [1-7]. The reconstruction methods based on bilateral and trilateral interpolation [5, 6] are not suitable for the system shown in fig.2, because the reconstruction method was specially designed for the spectral sensor developed in these papers, and the accurate registration between the RGB camera and the LRSS was needed. Thus we address the reconstruction methods introduced in [1, 2, 7] in this paper.

A. Full-frame Wiener estimation

Wiener estimation is a classical but powerful technique for spectral reconstruction. Using the covariance matrix of the spectral radiance or spectral reflectance, the spectral data at each pixel is linearly estimated. The covariance matrix represents the statistical characteristics of the target object, and it is possible to derive the covariance matrix using the spectral data captured by the LRSS [1]. Then the spectral estimation matrix can be adapted to target objects using the LRSS data. If LRSS data is not available, the covariance matrix needs to be determined without the measurement data, and it is known that a Markov model gives reasonable estimation accuracy [9]. The use of LRSS data enables to improve the estimation accuracy compared with this method, and they are compared in the experiment.

B. Piecewise Wiener estimation

A piecewise Wiener (PW) estimation technique [1] was developed for the hybrid resolution spectral imaging. In this method, the covariance matrix of the spectral reflectance is generated at each region in the high-resolution RGB image, using the spectral data obtained by the LRSS near the corresponding region. Then the matrices for Wiener estimation are generated and applied to those regions of the RGB image. Since the spectral estimation matrix is adapted to each region based on the spectral data measured by the LRSS, it provides remarkably better accuracy than conventional techniques.

C. Full-frame Multiple Regression

Although the PW estimation achieves high accuracy, it requires the spectral sensitivity of the RGB camera and if there is an error in the camera characterization, the spectral estimation accuracy is affected. On the other hand, a regression-based estimation technique [6] does not need the camera spectral sensitivity, and it was also adapted to the hybrid-resolution spectral imaging system [7]. In this method, the registration between the images from the RGB camera and the LRSS is performed at first. Then all the corresponding spectral radiance data and RGB data in a frame are used for the multiple regression. This method is called full-frame multiple regression (FFMR) hereafter. The RGB image data pixels are averaged to match the resolution with the LRSS image, where the requirement of the registration accuracy is not very severe. In this manner, the spectral reconstruction matrix is derived using the training data captured from the target scene, and we can expect high-accuracy in the spectral estimation.

D. Locally Weighted Multiple Regression

In the method described in the previous section, a single regression coefficient matrix is used for a whole image. However, when a variety of objects with different spectral characteristics are included in a frame, the accuracy of estimation is decreased. A method called locally weighted multiple regression (LWMR) [7] uses multiple matrices for spectral estimation depending on the positions in the images. Higher accuracy is expected since content adaptive estimation matrix can be employed in LWMR method.

IV. Experimental results

The system developed in this work consists of an RGB camera (resolution: 1280×1024 pixels) and the LRSS (68 pixels, spectral range: 380-780nm). The RGB camera and the LRSS are placed side-by-side as shown in fig. 2. We captured various objects and the spectral accuracy was evaluated by comparing the obtained spectral image with the spectral radiance and color measured by a spectroradiometer. We used three objects: Color chart (CChart), Toys, and Artificial flowers (Aflowers). As the spectral reflectance was obtained, it was possible to calculate the color under arbitrary illuminant. Table 1 shows the color difference in the estimated color under D50. It can be confirmed that the LWMR gives the highest accuracy. The reason why the accuracy in PW is not very high is considered to be the error in the spectral sensitivity of the RGB camera.

Table 1 Color estimation error (average CIELAB ΔE) in the estimated color under D50 from the spectral image captured under artificial sunlight (Seric Solax XC-100AF)

	Wiener (Markov)	Wiener (LRSS)	PW	FFMR	LWMR
Cchart	13.1	13.0	9.6	7.5	3.4
Toys	12.5	9.1	8.1	5.5	5.2
Aflowers	12.4	7.9	5.6	8.8	5.5

V. Conclusion

In this paper, we present the hybrid-resolution spectral imaging system and it is shown that the spectral estimation accuracy is improved utilizing regression-based technique.

To apply this system to the reproduction of highly realistic material appearance, we also implement a system with higher dynamic range, using 18bit monochromatic camera for LRSS and 18bit RGB camera. It is expected to enable the faithful reproduction of specular reflection in addition to the diffuse reflection component using the spectral image.

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