Two-Shot type 6-band still image capturing system using Commercial Digital Camera and Custom Color Filter

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Abstract

A practical 6-band still camera system for accurate color reproduction is presented. This camera system consists of a commercial digital camera and a customized color filter. Two 3-band images captured with and without the filter are used for color reproduction. Color reproduction process is carried out in GPU so that result image of color reproduction can be displayed on monitor interactively.

1. Introduction

Accurate color reproduction is required in imaging system for medical, electronic commerce, industrial design, digital archiving, and so on. Multispectral imaging is regarded as a solution for such applications and several types of multi-spectral image capturing system have been developed [1-4]. However, most of them have not been widely used in business activity. There are some reasons, but one is that constructing multispectral image capturing system costs a great deal of money.

In this paper, a practical 6-band still camera system for accurate color reproduction is presented. This camera system consists of a commercial digital camera and a customized color filter. The filter is attached in front of camera lens and is easy to be removed. Two images captured with filter and without filter are combined into a 6-band image. Color reproduction process using captured 6-band image is done using graphics processing unit (GPU) on graphics card of PC. Then, the color reproduction result can be seen on display monitor soon after loading the 6-band image into software.

Note that this principle of obtaining 6-band image and the estimation method has been published earlier [4]. The main contributions of this paper are technical development of a device that can take conveniently 6-band image and software that can confirm result of color reproduction interactively.

2. Developed system

2.1 Image capturing system

Figure 1 shows characteristic of custom color filter used in the 6-band image capturing system. The filter cut off the left side (short wavelength domain) of the peak of original spectral sensitivity of blue and red, and also cut off the right side (long wavelength domain) of the green's. Figure 2 shows a photo of the camera system. The filter attached in front of lens can be slide horizontally by hand. Two images are captured with the filter and without filter. Although the filter can be moved smoothly, there are some displacement errors between two images. For preventing this displacement error, the filter holder has attachment of tripod. The remaining error can be corrected in software.

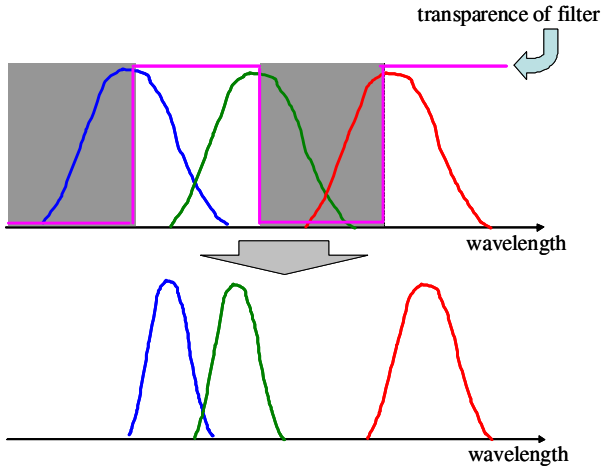

***Figure 1**. Characteristic of the custom color filter.*

***Figure 2**. 6-band image capturing system*

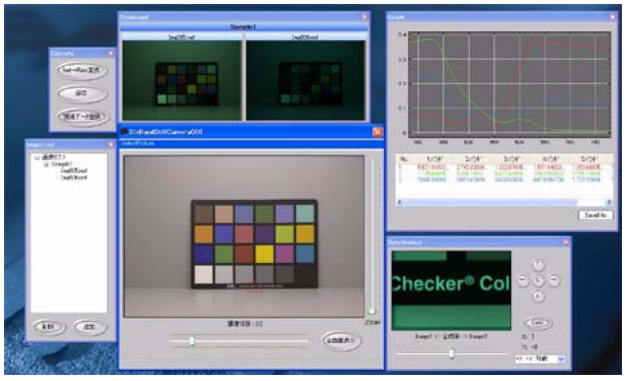

***Figure 3**. Software for color reproduction*

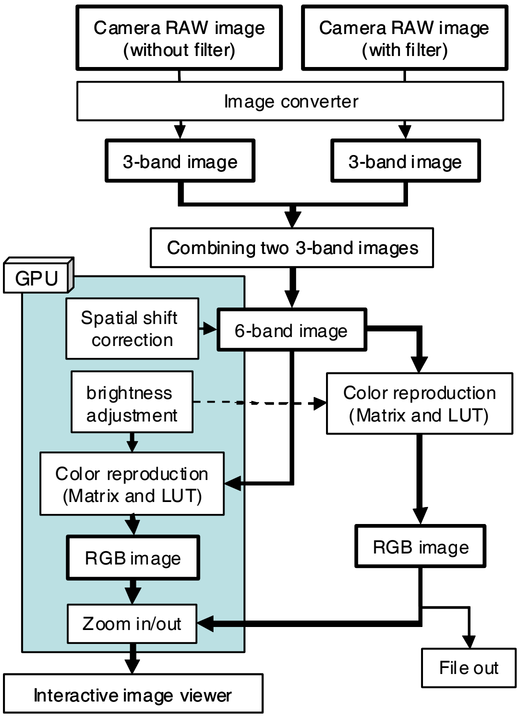

***Figure 4**. Diagram of software*

2.2 Software

Figure 3 shows GUI of the software for color reproduction. There are six windows; image list (left bottom), registration of parameters for color reproduction (left top), preview window (center bottom), thumbnail window (center top), displacement error collection (right bottom), and spectral reflectance viewer (right top). Here, parameters for color reproduction mean wiener matrix for estimating spectral reflectance, spectrum of destination illumination, and primary colors and tone curve of display monitor. Spectral reflectance is estimated based on the wiener estimation. As for the algorithm of spectral estimation, please refer some previous study [5].

Figure 4 shows a diagram of this software. A feature of the software is real-time color reproduction processing using Graphics Processing Unit (GPU) of graphics board on computer. Then, resultant image can be seen soon after reading 6-band image or after changing destination illumination. And also, brightness collection of resultant image and zooming in/out can be done interactively. Calculation of color reproduction can be also done by using CPU for obtaining more accurate result rather than calculation by using GPU.

Resultant image can be written out as 16-bit CIE-XYZ or CIE-Lab image (monitor independent color), and also bmp, jpeg and 16-bit raw image file (monitor dependent color). As for bmp and jpeg file, the resultant image can be handled on Adobe Photoshop^{TM} by combining ICC profile of using display.

3. Experiments

NIKON D200 is used for image sensor. This camera can write out raw image from CCD sensor. The signal depth of captured image is 12bit for each color. The custom color filter is attached in front of lens. Figure 5 shows the measured spectral sensitivity of this image capturing system. The straight line described original spectral sensitivities of the sensor, and

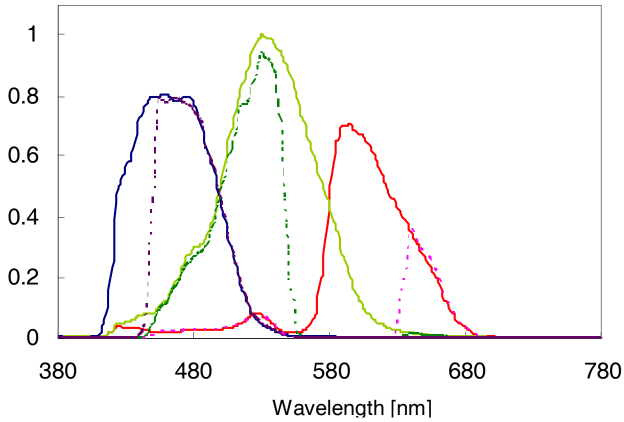

***Figure 5**. Measured spectral sensitivity of 6-band image capturing system.*

	1	2	3	4	5	6
6band	0.83	1.53	1.10	2.61	0.78	2.44
3band	0.96	2.81	2.35	3.76	2.73	3.05
	7	8	9	10	11	12
6ba	1.6	1.3	1.6	1.2	2.7	2.2

***Figure 6**. Evaluation of color difference.*

the dash line described the spectral sensitivity of sensor with the custom color filter.

For evaluating ability of color reproduction of the developed 6-band camera system, color difference (ΔE_{ab}) between target object and estimation result. Here, Macbeth Color Checker was used for target object. Using the 6-band camera system, images with the filter and without the filter were captured. As for reference, color reproduction using 3-band image (i.e. the image captured without filter) was also done. The calculated color differences are shown in Figure 6. It is confirmed that average of ΔE_{ab} was improved from 3.60 to

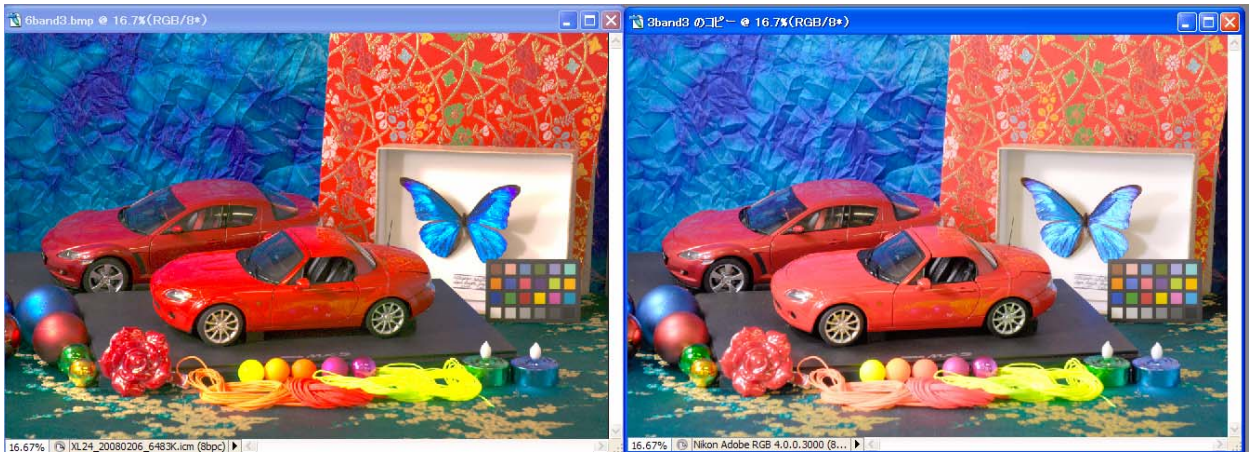

Figure 7. *Resultant images from 6-band (left) and 3-band (right) images*

1.91. This means that good result of color reproduction can be obtained by using 6-band image captured using the presented image capturing system.

4. Discussion

4.1 Color Range of 6-band camera system

Let us evaluate color range of the 6-band image capturing system. Figure 7 shows result image of color reproduction from 6-band image and 3-band image. Comparing these two images, vividness of red (car) and blue (butterfly) is lost in the result image from 3-band. On the other hand, color of Macbeth color checker in both image are almost same. This means that 6-band image capturing system has color range wider than 3-band image capturing system. Figure 8 shows color range of 6-band and 3-band system (under sunlight) projected on u'-v' chromaticity diagram. Color gamut of adobe RGB is also shown on the diagram as reference. This shows that 6-band capturing system has wider color range than adobe RGB, especially red and blue.

4.2 Spectral sensitivity of camera

In the experiments, NIKON D200 was used for image sensor. As additional experiments, spectral sensitivities of other several digital cameras were measured. Measurement results of NIKON D3, CANON EOS 1D Mark III and Olympus E-410 are shown in Figure 10. Although a little different among the sensitivities exist, they have almost same characteristics. One of common feature is that there is no sensitivity over 700nm because of IR cut filter. This causes estimation error of spectral reflectance of near IR wavelength.

In order to confirm affects of IR cut filter in estimating spectral reflectance, simulation of estimating spectral reflectance from 6-band data captured with IR cut filter and without IR cut filter are done. Then RMSE of spectral reflectance are calculated. The results are shown in Figure 9 and say that using near IR wavelength information contributes to improve accuracy of estimating spectral reflectance.

5. Summary

A reasonable and practical 6-band still image capturing system was developed and experimental results show its possibility for accurate color reproduction. In most simple case (needless to estimate spectral reflectance, just only color), it becomes more easily to collect 6-band image at out side of laboratory or photo studio. PC and power supplying equipment are not necessary, just camera, filter and tripod are required. When estimating spectral reflectance is required, illumination spectrum is measured by using portable spectrometer (e.g. x-rite i1-pro) connected to notebook PC.

Currently, total system of image capturing, color reproduction software, color reproduction on display monitor and color reproduction using commercial ink-jet printer as printed material have being developing (see Figure 11).

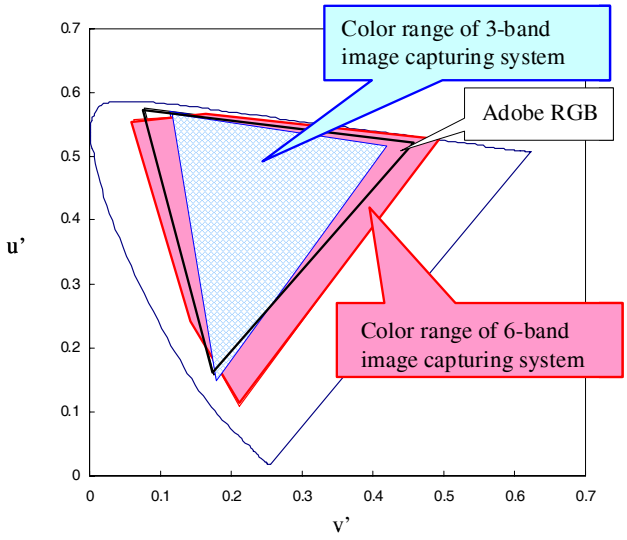

Figure 8. *Color range of 6-band capturing system*

	6-band with IR cut filter	6-band without IR cut filter
Avg.	1.46	0.82
Max.	3.35	1.81
Min.	0.36	0.25
Std. Dev.	0.75	0.36

Figure 9. *RMSE of spectral reflectance (simulation result)*

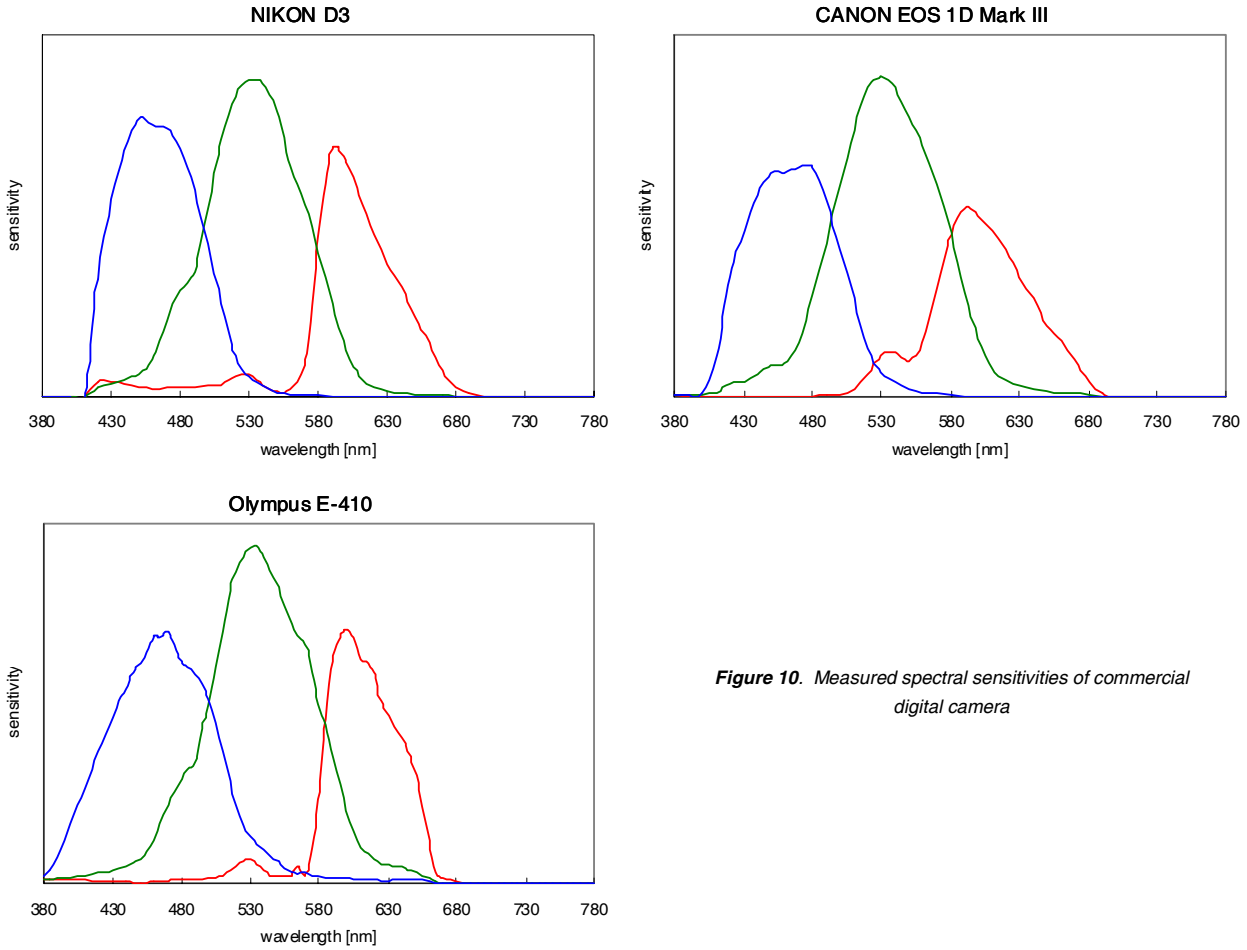

***Figure 10**. Measured spectral sensitivities of commercial digital camera*

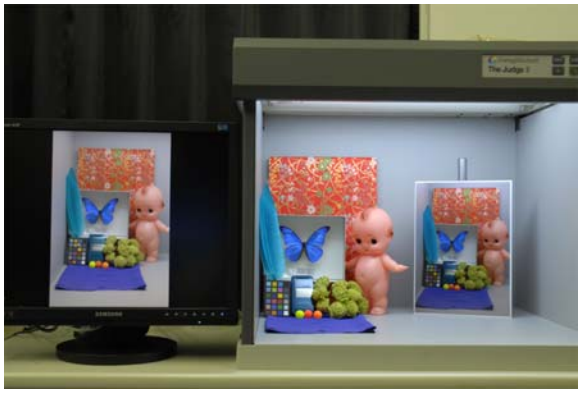

***Figure 11**. Color reproduction as printed material.*

Acknowledgment

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Author Biography

Masaru Hashimoto received his Ph.D. degree in Engineer from the Tokyo Institute of Technology, Japan in 2002. He joined NTT Communication Science Laboratories in 2002. Since 2003 he has worked in NTT DATA Corporation. And he joined Natural Vision project of National institute of information and communications technology, Japan in 2003 to 2005. His research interests include 3-D image display, computer vision, image recognition and multi-spectral imaging.