# A stereo nine-band camera for accurate color and spectrum reproduction

Masaru Tsuchida, Takahito Kawanishi, Kunio Kashino, Junji Yamato

NTT Communication Science Laboratories, NTT Corporation

## 1. Introduction

In the digital archiving for cultural heritage preservation, in the medical field, and in some industrial fields, high-fidelity color reproduction is very important. Multiband imaging technology is a solution for accurate color reproduction. Although several types of multiband camera systems have been developed, all of them are multi-shot systems and they cannot take images of moving objects. Tsuchida et al. [2010] have developed a one-shot stereo six-band camera system using two commercial digital cameras. This system is very reasonable in terms of cost, but the distance between the cameras causes self occlusion disparity problems when the object has 3D shape. In addition, the number of color channels of camera system should be increased for further improvement of the accuracy of estimated spectral reflectance. In this paper, we propose a stereo nine-band camera consisting of nine monochrome cameras with nine different interference filters. A nine-band image is generated from nine stereo images captured by this system. Estimated spectral reflectance and reproduced color images reproduced in experiments are shown.

## 2. Camera system

Figure.1 shows our camera system and its spectral sensitivities. Visible wave length is divided into nine with little overlap, and the eighth and ninth bands cover infrared. The distance between the optical axis of each camera is 55 mm. Captured image size is 2-M pixels (1600 x 1200) and the bit-depth of signal is 10 bits. Each camera is connected to a PC with IEEE 1394b cable. The frame rate of image transfer is 15 fps at maximum for a full-size image, but 30 fps can be achieved when image size is reduced to 1024 x 768 pixels (XGA). All cameras are synchronized and images of moving objects can be taken as still- or moving images.

## 3. Generating nine-band image from stereo image

In order to generate a nine-band image from the stereo image captured with our system, eight images have to be aligned into a reference image. Let the image of the center camera be the reference image. The image generation in this paper is based on an image transformation technique. In the future, 3D depth information estimated from stereo images will also be used, which will make the quality of the image generated in each band much better.

When an image-set of 2D object like a painting or tapestry is taken, a projective transformation is useful for aligning the position of each channel image. When 3D objects are taken, it is better to use nonlinear transformation. In this work, thin-plate spline approximation (TPS) was applied for this purpose [Tsuchida 2011]. To calculate transformation parameters, corresponding points between the two images are detected by using the phase-only correlation (POC) method [Takita 2003]. POC is a scale- and rotation-invariant pattern detection method that uses phase information. The resultant nine monochrome images are combined into a nine-band image. The nine-band image is converted into a spectral reflectance image through Wiener estimation [Pratt 1976], and, the spectral reflectance image is converted into a RGB image by using the measured illumination spectrum and monitor characteristics.

## 4. Experimental results and summary

First, we confirmed the accuracy of the estimated spectral reflectance by comparing it with reflectance measured with a spectrometer. As a target object, we used Macbeth ColorChecker$^{TM}$. Figures.2 and 3 show a part of the measured and estimated spectral reflectance. Although some errors are found in the short-wavelength domain between 380 to 420 nm, spectral reflectance seems to be well estimated using the proposed camera system. These errors were caused by a lack of camera sensitivity in this wavelength domain.

Next, images of 2D and 3D objects were taken with this system. Each channel image of captured nine-band image of 2D object (woodblock print) is shown in Fig.4. Final images after image transformations and color reproduction of the images of the 2D and 3D objects are also shown in Fig. 4. We compared the color of the real object and that of image displayed on a LCD monitor by eye and spectrometer, and confirmed that the object color is well reproduced. The resultant image was compared with the image obtained with two-shot six-band system [Hashimoto 2008], and it was confirmed that both results have the same color quality as the real object.

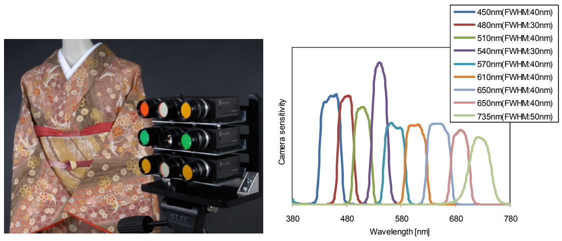


Figure 1 Stereo nine-band camera and its spectral sensitivity.

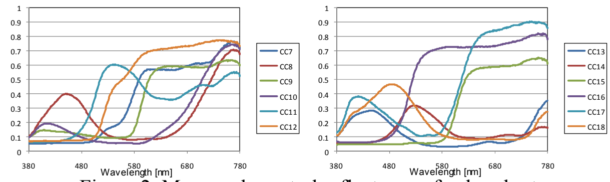


Figure 2. Measured spectral reflectance of color chart

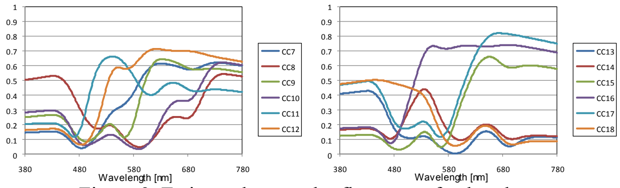


Figure 3. Estimated spectral reflectance of color chart



Figure 4. Captured nine-band images and color reproduction results (2D and 3D objects).

## References

TSUCHIDA, M., et al., 2010. A stereo one-shot multi-band camera system for accurate color reproduction. *In proceedings of Siggraph, Poster, ACM.*

TSUCHIDA, M., et al., 2011. Evaluating Color Reproduction Accuracy of Stereo One-shot Six-band Camera System. *In proceedings of 19th Color and Imaging Conference (CIC19).*

TAKITA, H., et al., 2003. High-accuracy image registration based on phase-only correlation. *IEICE Transaction of Fundamentals, Vol. E86-A, no.8, 1925-1934.*

PRATT, W. K., et al., 1976. Spectral estimation techniques for the spectral calibration of a color image scanner. *Applied Optics, OSA, 15, 73–75.*

HASHIMOTO, M., 2008. Two-Shot type 6-band still image capturing system using Commercial Digital Camera and Custom Color Filter. *In proceedings of Fourth European Conference on Colour in Graphics, Imaging, and Vision (CGIV2008).*



SIGGRAPH 2012, Los Angeles, California, August 5 – 9, 2012.
ISBN 978-1-4503-1435-0/12/0008