

## Real-time multispectral and multiprimary video system

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### ABSTRACT

In this paper, we present a real-time multispectral and multiprimary video system composed of 6-band HDTV camera and 6-primary display, for high fidelity and wide-gamut color reproduction. The 6-channel image signal captured by 6-band HDTV camera is converted to 3-channel encoding colorimetric signal by a 6x3 matrix multiplication in 6to3 color converter, 3-channel signal is converted to 6-primary display signal by 3D lookup table (LUT) in 3to6 color converter, and the image is reproduced on 6-primary display in real-time. In the experimental evaluation using the GretagMachbeth ColorChecker as the object, the color differences (CIE  $\Delta E_{ab}^*$ ) between the real-time reproduction of color image and the original color of the objects attained 3.08 on average and 4.71 on maximum. Moreover, the additional experiment are done by using the 86 color patches provided by ITE (Institute of Technical Electronics), Aachen University of Technology as the object to confirm the ability of wide gamut color reproduction. As a result, the colors out of the gamut of a conventional display are successfully reproduced by this system.

### 1. INTRODUCTION

Recent advancement of multimedia technology introduced the possibility to realize electronic art museum, electronic commerce, telemedicine, and so on. In such systems the reproduction of high-fidelity color image is one of most important technology. But it is not possible to reproduce high-fidelity color image by means of the current RGB-based color imaging system.

On the other hand, multispectral imaging, which is significant technology for the acquisition and display of accurate color information, has been actively studied. Natural Vision Project (NV) [1] has developed spectrum-based Color Reproduction System for the high fidelity color reproduction of the objects through color image communication systems. The system facilitates the reproduction of color image under arbitrary illuminant, which may be different from the image-capturing environment, by the multispectral image capture. And multiprimary color display, i.e., using more than three primary colors has been also developed for the reproduction of expanded color-gamut. In addition, for a multispectral motion picture system, we have developed a 6-band HDTV camera<sup>[2]</sup>. In this paper, a real time video system composed of a 6-band HDTV camera and a 6-primary display is introduced. The system implementation and experimental results are reported.

### 2. System implementation

The real-time video system is composed of a 6-band HDTV<sup>[2]</sup> camera, the 6to3 and 3to6 color converters, and a 6-primary DLP projection display<sup>[3]</sup>, as shown in figure 1.

The multispectral image signal ( $g_i$ ) captured by the 6-band HDTV camera is given by

$$g'_i = \int h_i(\lambda) e_r(\lambda) f(\lambda) d\lambda \quad (i = 1, 2 \dots 6) \quad (1)$$

$$g_i = \gamma_i(g'_i) + g_{i0} \quad (2)$$

where  $h_i(\lambda)$  is the spectral sensitivity of i-th channel of the 6-band HDTV camera,  $e_r(\lambda)$  is the spectral intensity of the illumination light, and  $f(\lambda)$  is the spectral reflectance of the object.  $\gamma_i(\cdot)$  represents the tone curve of the camera. The multispectral image signal is converted to the encoding

colorimetric signal through 3 steps by the 6to3 color converter, which consists of a 1D lookup table (LUT), a 6x3 matrix multiplication, and an optional 1D LUT. The 6to3 color converter can process the image signal (image size: 1920 by 1080 / channel) in real-time. The multispectral image signal  $g_i$  is converted to  $g'_i$  by 1D LUT based on eq. (2) for the correction of dark current noise and the tone curve of the camera, and  $g'_i$  is converted to the encoding colorimetric signal ( $\mathbf{c}$ ) by a 6x3 matrix ( $\mathbf{MW}$ ) multiplication, as

$$\mathbf{c} = \mathbf{MWg}' \quad (3)$$

where  $\mathbf{W}$  is designed by a Wiener estimation of spectral reflectance and the calculation of the CIE 1931 XYZ tristimulus value under the observation illuminant, as follows

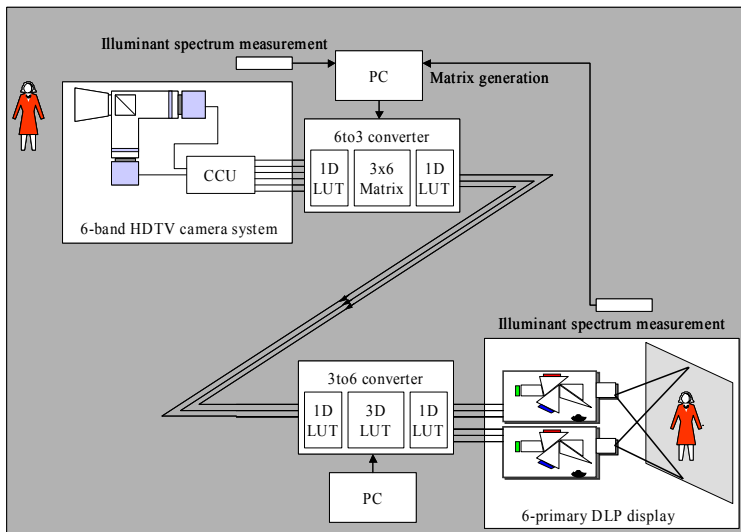
$$\mathbf{W} = \mathbf{AB}^{-1}$$

$$\mathbf{A}_{ij} = \int \int e_o(\lambda) \cdot x_i(\lambda) \cdot E[f(\lambda) \cdot f(\lambda')] \cdot e_r(\lambda') \cdot h_j(\lambda') \cdot d\lambda \cdot d\lambda' \quad (4)$$

$$\mathbf{B}_{ij} = \int \int e_r(\lambda) \cdot h_i(\lambda) \cdot E[f(\lambda) \cdot f(\lambda')] \cdot e_r(\lambda') \cdot h_j(\lambda') \cdot d\lambda \cdot d\lambda'$$

where  $e_o(\lambda)$  is spectral intensity of the illumination at the observing environment,  $x_i(\lambda)$  is the CIE 1931 XYZ color matching function and  $E[f(\lambda) \cdot f(\lambda')]$  is the autocorrelation function of the spectral reflectance of the object. The XYZ tristimulus value is converted to the encoding colorimetric signal in another color space by multiplying the 3x3 matrix ( $\mathbf{M}$ ), because the CIE XYZ color space is inefficient in encoding the colorimetric signal. The processors used in this experimental system deal with only positive value signals and the encoding colorimetric signal must be encoded by a wide-gamut trichromatic system. As the triangle spanned by the three primary colors include the color-gamut of a six-primary display on the chromaticity plane, the three primary colors of the color space of the encoding colorimetric signal are selected, as shown in figure 5. The chromaticity coordinates of the primary colors are  $(x, y) = (0.705, 0.294)$ ,  $(0.05, 0.93)$  and  $(0.05, -0.05)$ . The better selection of the color space for the encoding colorimetric signal is one of future works. The matrix based on eqs. (3) and (4) in the 6to3 color converter is generated using the spectral intensities of the illumination lights at both image capturing and display environment. Then the color of the objects under the observation illuminant, which may be different from the image-capturing environment, is reproduced by real-time color conversion.

The 3-channel encoding colorimetric signal is converted to the 6-primary display signal through 3 steps by the 3to6 color converter, which is composed of a 1D LUT, a 3D LUT, and an additional 1D LUT. The 3to6 color converter also can process the image signal (image size: 1920 by 1080 / channel) in real-time. The former 1D LUT converts the 10bit signal to 8bit, because the



**Figure 1:** System configuration of the real time video system based on spectral information.



**Figure 2:** 6-band HDTV camera.



**Figure 3:** 6-primary DLP projection display.

following 3D LUT only accepts 8bit signal. The 3D LUT is designed by a multiprimary color conversion method<sup>[4-6]</sup> called Linear Interpolation on Equi-luminance Plane<sup>[4]</sup>, though several methods have been proposed. The 3D LUT is based on the table interpolation method, where the signal is interpolated from 17x17x17 lattice points. The latter 1D LUT corrects the tone reproduction curve of the 6-primary DLP display.

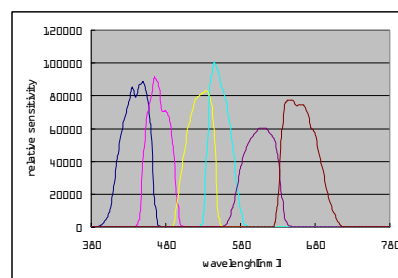
### 3. RESULTS

A live multispectral and multiprimary video reproduction is done by the experimental system described above. The 6-band HDTV camera and the 6-primary DLP projection display used in our experiment are shown in figure 2 and figure 3. The spectral sensitivities of the 6-band HDTV camera are shown in figure 4. The objects are 24 color patches included in GretagMacbeth ColorChecker and 86 color patches provided by ITE (Institute of Technical Electronics), Aachen University of Technology (as shown in fig.1). Vivid colors, which are out of the gamut of conventional display, are included in the ITE-Aachen 86 patches. The spectral intensity of the illumination used in this experiment, the colorimetric values of 24 color patches in GretagMacbeth ColorChecker and ITE-Aachen 86 patches are measured by the spectroradiometer TOPCON SR-2 with the measuring wavelength interval of 5 nm from 380 nm to 780 nm. The two objects are illuminated under a kind of xenon lamp whose spectral distribution is similar to standard D65. The two objects are captured by the 6-band HDTV camera and reproduced the color of the objects under the image capturing illuminant on the 6-primary DLP display in real-time respectively. The reproduction of color image on the 6-primary DLP display is also measured by the spectroradiometer. Moreover, to compare the capability of the accurate color reproduction of this system and that of conventional HDTV system, the same objects are reproduced by using a conventional HDTV system composed of a HDTV camera (HDL-37E Ikegami) and a three-primary DLP display (TH-D9610J Panasonic) under the same condition, and reproduced colors are measured by the spectroradiometer. The average and maximum color differences ( $CIE \Delta E_{ab}^*$ ) between the original color of the objects and reproduction of color image using two systems are shown in table1. It is confirmed that the multispectral and multiprimary video system is done successfully and reproduce the more accurate color than the conventional HDTV system. The results of the several color patches among ITE-Aachen 86 patches are shown in table2 and in figure 6. The colorimetric values, which are the outside of conventional display gamut, are successfully reproduced.

### 4. Discussion

The multispectral and multiprimary video system can reproduce the more accurate color than the conventional HDTV system, because the color patches outside the gamut of conventional display cannot be reproduced correctly by the conventional HDTV system. Moreover, using 49 color patches among ITE-Aachen 86 patches, which are inside of the gamut of conventional display, the average color differences of the multispectral and multiprimary system and the conventional HDTV system are 4.04 and 5.40 respectively. The result shows that the 6-band HDV camera can estimate more accurate color than a conventional RGB (i.e. 3-band) HDTV camera. However, errors of color reproduction are still relatively large, and the possible sources of errors are listed as follows;

- The characterization error of the six-band camera is not small enough when it is operated in real-time mode.



**Figure 4:** Spectral sensitivity of the 6-band HDTV camera



**Figure 5:** ITE-Aachen 86 patches

- As the image signal is processed by 10bit or 8bit in the color converters, quantization errors are accumulated.
- The selection of color space for the output of 6to3 color converter also affects the accuracy of color reproduction.
- The interpolation is done in 3D LUT from small number of lattice points.

**Table 1:** Color reproduction errors (CIE  $\Delta E a^* b^*$ ) in the experiments

#	GretagMacbeth ColorChecker		ITE-Aachen 86 patches	
	Average	Maximum	Average	Maximum
Multispectral and multiprimary video system	3.08	4.71	4.04	9.63
Conventional HDTV system	4.64	10.43	8.05	26.70

## 5. CONCLUSIONS

We introduced system implementation of the real-time multispectral and multiprimary video system. This system enables real-time, high fidelity, wide gamut color reproduction. Through the preliminary experiment, it is confirmed that the real-time multispectral and multiprimary video system with 6-band HDTV camera and 6-primary display can reproduce the more accurate color than conventional HDTV system, although the errors of color reproduction are still relatively large. Moreover the colors of the outside of the conventional displays gamut are successfully reproduced.

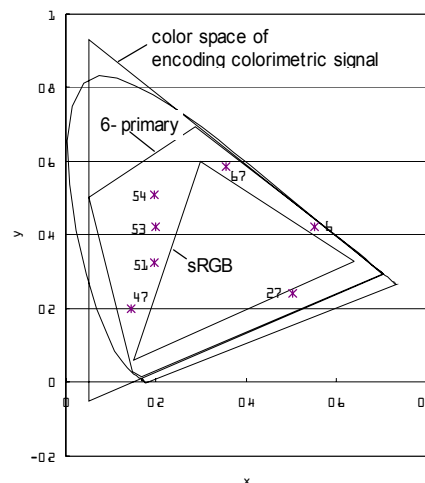
This system is based on the spectrum-based color reproduction system, where the colorimetry under the observation illuminant is estimated from the multispectral image. Thus the numbers of channels in image capturing and display are independent, although 6-channel devices are used in this experiment. As the future work, after the improvement of the system at the points of above discussion for higher accuracy, the image encoding and transmission scheme will be incorporated.

## References

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**Table 2:** Color reproduction errors (CIE  $\Delta E a^* b^*$ ) of several patches, which are the outside of conventional display gamut.

#	Conventional HDTV System	Multispectral and multiprimary video system
6	11.73	7.89
27	11.51	5.86
47	20.31	2.83
51	13.57	4.26
53	19.96	5.03
54	23.51	0.95
67	4.03	1.50

**Figure 5:** The color gamut of the 6-primary DLP and sRGB display on CIE xy chromaticity diagram. The color coordinates of the several patches are also shown. The numbers marked in the graph correspond to the ones in table 2.