Real-time video reproduction using six-band HDTV camera and six-primary display

Masahiro Yamaguchi[1)3)*)], Masanori Mitsui[2)], Ryo Iwama[3)], Hideaki Haneishi[3)4)] and Nagaaki Ohyama[2)3)]

1) Tokyo Institute of Technology, Imaging Science and Engineering Lab.
2) Tokyo Institute of Technology, Frontier Collaborative Research Ctr.
3) Akasaka Natural Vision Research Ctr., NICT, Japan
4) Chiba University, Frontier Medical Research Center
*) E-mail: *guchi@isl.titech.ac.jp*

1. Background and purpose

The color reproduction accuracy is limited in conventional RGB-based video systems. Multispectral imaging technique is promising for the high-accuracy color reproduction, but it has been applied mainly to still images. Multiprimary color displays are also developed to expand the range of reproducible colors. To actualize an innovative imaging system based on multispectral and multiprimary technology, a multiprimary video system is under development in Natural Vision project[1-4] but real-time reproduction has not been reported up to now.

In this paper we present a real-time video system using six-band HDTV camera[1] and six-primary display[2]. The video system enables the high fidelity and wide gamut color reproduction of original object, under arbitrary illuminant, which may be different from the image-capturing environment. Preliminary result of the experimental system is reported.

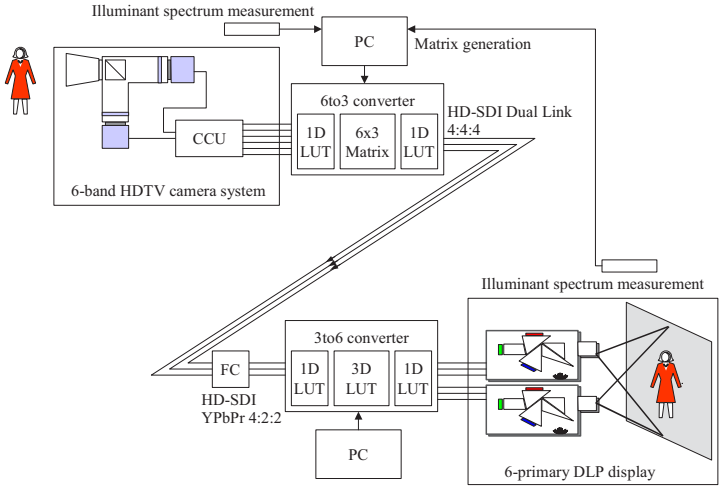

Fig.1 System configuration of the real-time video system using 6-band HDTV camera and 6-primary color display. FC:Format converter (4:4:4 to 4:2:2)

Fig.2 6-band HDTV camera.

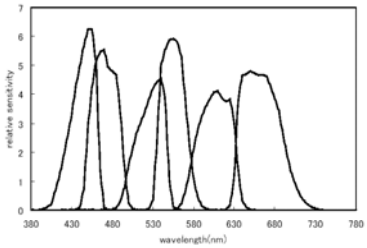

Fig.3 Spectral sensitivities of 6-band HDTV camera.

2. System

The multiprimary video system is composed of a 6-band HDTV camera[1], 6to3 and 3to6 color converters and a 6-primary projection display[2], as shown in fig.1. The 6-band HDTV camera (Fig.2) has been built with two commercial HDTV camera modules and a branched optical system, where two interference filters are attached, such that the spectral sensitivities of the camera are modified as shown in fig.3. The camera control unit (CCU) outputs 6-channel uncompressed video signal without sub-sampling of chroma data (4:4:4 data) in the form of two Dual-Link 4:4:4 HD-SDI (High-definition Serial Digital Interface) video streams. Then the output image is 6-channel, 10 bit data in 1920 by 1080 pixels / channel.

The 6-channel image signal is converted to 3-channel colorimetric signal through three steps: a 1D lookup table (LUT) for the correction of dark-current noise and the tone curve of the camera, a 6x3 matrix multiplication, and an optional 1D LUT for the output of 3-channel signal. The 6x3 matrix estimates the color under a specified illuminant, designed using the spectral sensitivity of 6-band camera, the spectral energy distributions of image capturing and display environments.

The 3-channel colorimetric signal must be positive value due to the limitation of current devices. The colorimetric signal is thus encoded such that the gamut of 6-primary display is included in the triangle spanned by three vectors in the chromaticity plane as shown in fig.4. The chromaticity coordinates of the three vectors are (x, y) = (0.705, 0.294), (0.050, 0.930), (0.050, -0.050). The optimization of the colorimetric signal encoding is a subject for future consideration.

The 3to6 converter has input interfaces for HD-SDI YPbPr 4:2:2 format and TMDS (Transition Minimized Differential Signaling). The format converter before the 3to6 converter adapts the 4:4:4 Dual Link HD-SDI to the 4:2:2 single-link stream.

In the 3to6 converter, the 1D LUT before the 3D LUT converts the 10bit data to 8bit, because 3D LUT allows only 8bit signal. The 3D LUT consists of 17x17x17 lattice points, and the intermediate data is interpolated in video-rate. The 3D LUT can be designed by the multiprimary color conversion methods[5-7], while a method called LIQUID (Linear Interpolation on Equi-luminance Plane method)[5] is implemented in the following experiment. Since the lattice point of 3D LUT is not enough to render the color gamut of 6-primary DLP, the LIQUID method is applied to the control points outside of the display gamut, so as to correctly interpolate the colors near the gamut boundary. The tone reproduction curve of each channel of DLP is measured and implemented in the 1D LUT after the 3D LUT. The output signal of 3to6 converter is transferred to 6-primary DLP display, which comprises two modified DLP projectors. The color gamut volume of the 6-primary DLP display is 1.8 times larger than the conventional 3-primary DLP.

Table 1 The color differences between the original and the real-time reproduction. Commercial HDTV system vs. Multiprimary video system.

#	Object chromaticity		△Ea*b*	
	x	y	conventional HDTV system	multiprimary video system
18	0.4749	0.3033	8.85	8.37
49	0.1529	0.2153	17.60	2.83
53	0.2103	0.4084	19.30	4.76
54	0.2106	0.4802	20.92	10.09

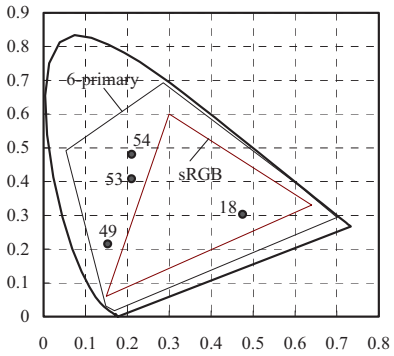

Fig.4 The color gamut of six-primary DLP and sRGB display on CIE xy chromaticity diagram. The color coordinates of the patches used in the experiment are also shown. (The numbers marked in the graph correspond to the ones in table 1.)

3. Results

A live reproduction of mutiprimary HDTV video is done by the system described above. The system enables real-time, high fidelity, wide gamut video reproduction by the use of spectrum-based color estimation, wide-gamut signal encoding, and mutiprimary display. Moreover, by changing the matrix in 6to3 converter, the color under different illuminant can be reproduced.

The 24 color patches from GretagMacbeth ColorChecker are reproduced by this experimental system and the average and maximum color differences (CIE ΔEa^*b^*) are 4.10 and 10.37, respectively. Additionally, to demonstrate the ability of wide-gamut color reproduction, several patches from the color chart provided by ITE(Institute of Technical Electronics), Aachen University of Technology, are reproduced by this system and commercial HDTV system. The results are shown in table 1 and fig.4. The color patches outside the gamut of conventional system can be successfully reproduced by this system.

The colorimetric reproduction error is still relatively large. The sources of error are listed as follows;

-- The interpolation is done by 3D LUT from only 17x17x17 control points, which are insufficient especially in the color around the edge of display gamut.

-- As the signals are processed by 10bit or 8bit integer format, quantization errors are accumulated. The truncation error in the matrix calculation is not negligible as well.

-- The selection of color space for 3-channel signal also affects the gray-level quantization. The color space for the output of 6to3 color converter can be selected so as to efficiently encode the wide-gamut colorimetric signal.

Although the color reproduction accuracy is still limited due to above error factors, it is confirmed that the real-time multiprimary video system shown in fig.1 works well through the experiment.

Through this preliminary experiment, the ability of the multiprimary video system is demonstrated, i.e., high-fidelity and wide-gamut color image reproduction, and the reproduction of the color under the different illuminant, whereas the issues for future investigation are also revealed.

4. References

1. K. Ohsawa, T. Ajito, H. Fukuda, Y. Komiya, H. Haneishi, M. Yamaguchi, and N. Ohyama, J. Imaging Science and Technology, 48, 2 (2004) 85-92
2. H. Motomura, N. Ohyama, M. Yamaguchi, H. Haneishi, K. Kanamori, S. Sannohe, Eurodisplay (2002) 563-566
3. N. Ohyama, M. Yamaguchi, H. Haneishi, IDW '02, (2002) 11-14
4. M. Yamaguchi, T. Teraji, K. Ohsawa, T. Uchiyama, H. Motomura, Y. Murakami, and N. Ohyama, Proc. SPIE, 4663 (2002) 15-26
5. H. Motomura, J. Int. SID, 11, 2 (2003) 371-378
6. T. Ajito, K. Ohsawa, T. Obi, M. Yamaguchi, and N. Ohyama, Optical Review, 8, 3, (2001) 191-197
7. F. König, K. Ohsawa, M. Yamaguchi, N. Ohyama and B. Hill, Proc. PICS conference (2002) 215-220
8. K. Kanamori, H. Kotera, O. Yamada, H. Motomura, R. Iikawa and T. Fumoto, Journal of Electronic Imaging, 2, (1993) 213-224