



# Six-band HDTV camera system for color reproduction based on spectral information

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# Abstract

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- ◆ Presenting the architecture of 6-band HDTV camera system
- ◆ Evaluating the accuracy of the color estimations
  - 6-band and conventional RGB HDTV camera
  - Using simulated and experimental camera signal

# Introduction

## ◆ Current color imaging system

– Based on RGB camera and RGB display

- Difficult to achieve the accurate color estimation of objects under arbitrary illumination
- Deviation between the spectral sensitivities of camera sensor and human vision

## ◆ Increasing the band number of input device

– Possible to estimate the object color more accurately under arbitrary illumination spectrum



# Architecture of the 6-band camera system

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- ◆ Constitution of the 6-band camera system
  - 6-band camera
  - Camera control unit (CCU)
  - Data storage

## ◆ 6-band HDTV camera

- Objective lens, L-shape branch connection optical unit, and two sets of HDTV camera heads

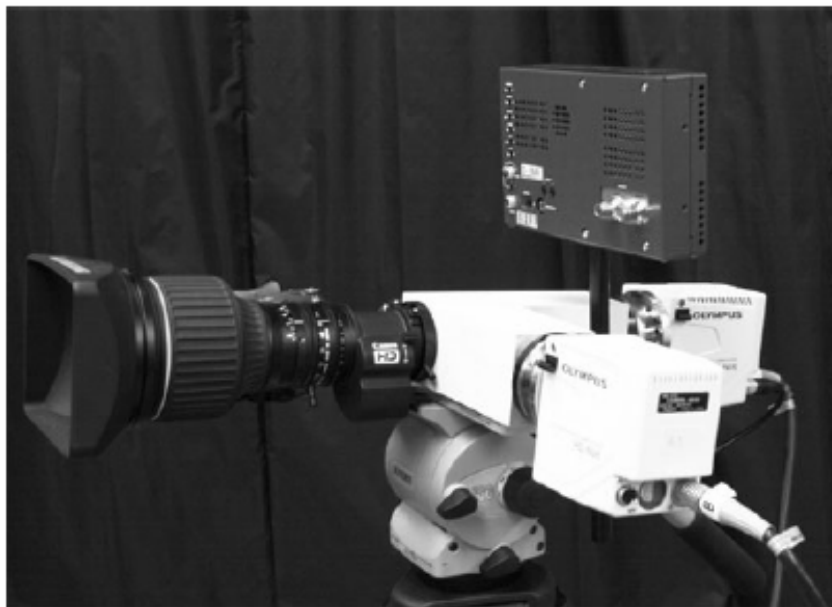


Fig. 1. 6-band HDTV camera.

- Schematic diagram of 6-band HDTV camera

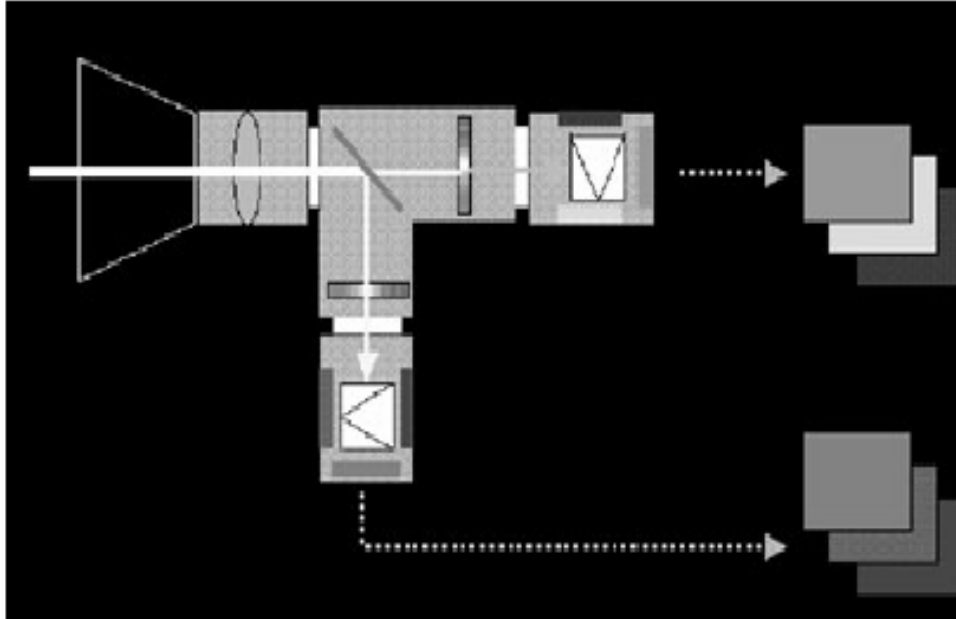


Fig. 2. Schematic diagram of 6-band HDTV camera architecture.

## – Spectral transmittances and sensitivities

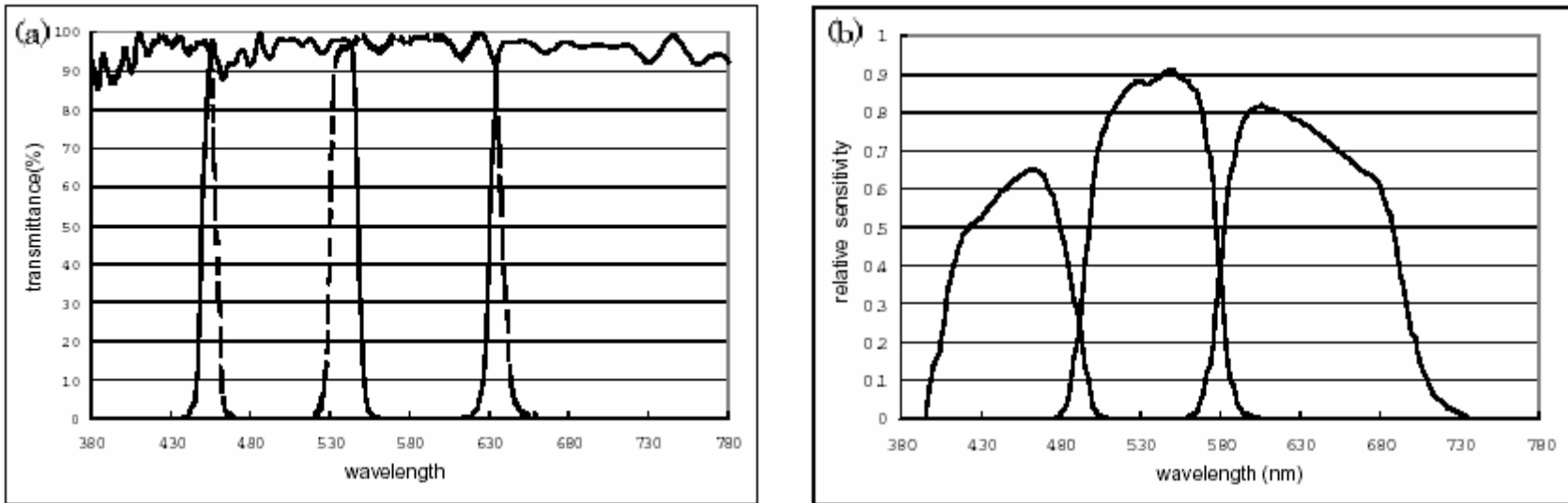


Fig. 3. Spectral characteristics (a) Spectral transmittance of 6-band separation filters (b) Spectral sensitivities of the HDTV camera.

- Location for the setting of the filter

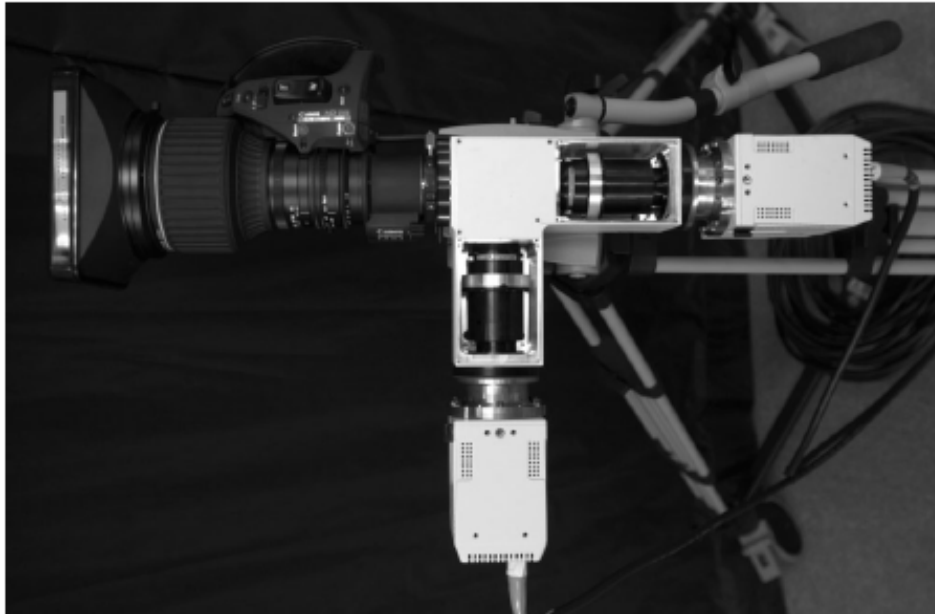


Fig. 4. The 6-band separation filter location in the 6-band camera.



## ◆ CCU and data storage architecture

### – Camera control unit (CCU)

- Two set of CCU for use of HDTV camera in sync
- Setting off the knee and gamma characteristics

### – Data storage

- 2.5 TB data capability

# Camera characterization

## ◆ Measurement of spectral sensitivity

- Measured by a narrow-spectrum light emitter and a spectrophotometer
- The spectral sensitivity

$$h_i(\lambda) = (g_{i\lambda} - g_{i0}) / l_\lambda \quad (1)$$

$l_\lambda$  : Light energy measured by the spectrophotometer

$g_{i0}$  : Bias signal

- Spectral sensitivities of the 6-band camera and conventional HDTV camera

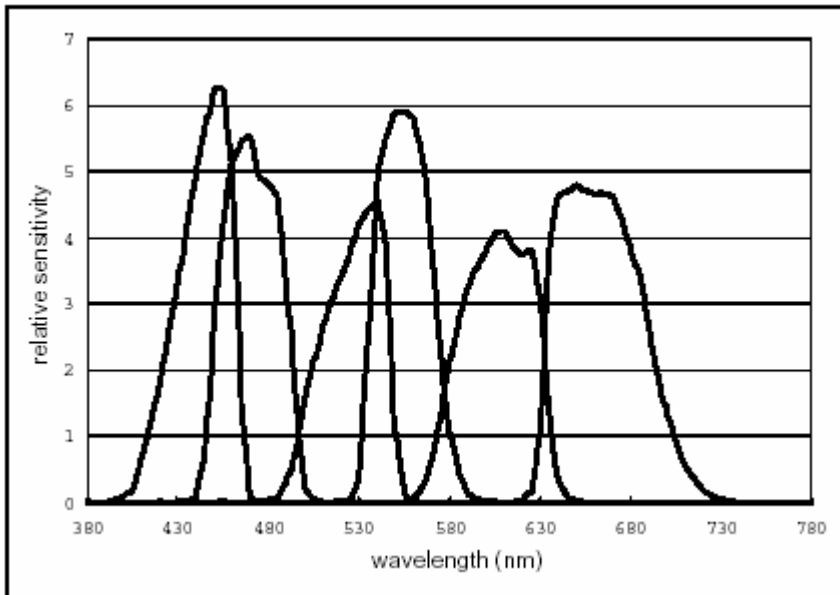


Fig. 5(a). Spectral sensitivities of the 6-band camera.

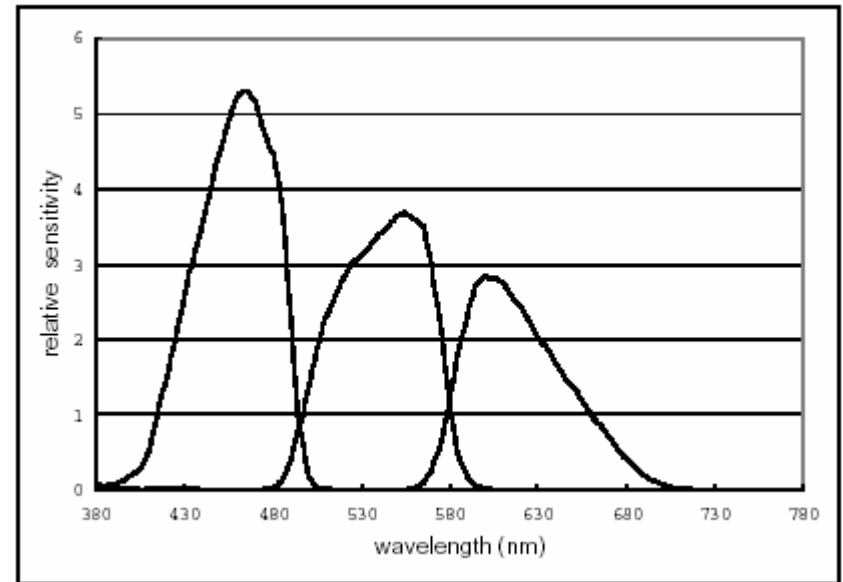


Fig. 5(b). Spectral sensitivities of the RGB camera.

## ◆ Mathematical camera model

- Adopting the mathematical camera model

$$g'_i = \int_{\lambda=380}^{780} h_i(\lambda) E(\lambda) f(\lambda) d\lambda \quad (i=1 \sim 6) \quad (2)$$

$h_i(\lambda)$ : Spectral sensitivities of the 6-band camera

$E(\lambda)$ : Illumination spectrum

$f(\lambda)$ : Spectral reflectance of the object

$$g_i = r_i(g'_i) + g_{i0} \quad (3)$$

$r_i(\cdot)$ : Gamma function of the camera

# Theory for accurate color reproduction

## ◆ CIE colorimetric value

$$X = \int_{\lambda=380}^{780} x(\lambda)E'(\lambda)f(\lambda)d\lambda \quad (4a)$$

$$Y = \int_{\lambda=380}^{780} y(\lambda)E'(\lambda)f(\lambda)d\lambda \quad (4b)$$

$$Z = \int_{\lambda=380}^{780} z(\lambda)E'(\lambda)f(\lambda)d\lambda \quad (4c)$$

$$\tilde{C} = MG \quad (5)$$

$$\tilde{C} = [\tilde{X}, \tilde{Y}, \tilde{Z}]^t, \quad G = [g_1, g_2, \dots, g_L]^t$$

## ◆ Determining the matrix M

- Minimizing  $\|\tilde{C} - C\|$  ,  $C = [X, Y, Z]^t$
- Rewritten as

$$M = AB^{-1} \quad (6)$$

$$a_{ik} = \int_{\lambda=380}^{780} \int_{\lambda'=380}^{780} c_i(\lambda) E'(\lambda) \langle f(\lambda) f(\lambda') \rangle h_k(\lambda') E(\lambda') d\lambda d\lambda' \quad (7)$$

$$b_{jk} = \int_{\lambda=380}^{780} \int_{\lambda'=380}^{780} h_j(\lambda) E(\lambda) \langle f(\lambda) f(\lambda') \rangle h_k(\lambda') E(\lambda') d\lambda d\lambda' \quad (8)$$

$\langle \rangle$ : Operator of ensemble average

$$c_1(\lambda) = x(\lambda), c_2(\lambda) = y(\lambda), c_3(\lambda) = z(\lambda)$$

# Results

## ◆ Simulation result

- Spectral reflectance of the color chart

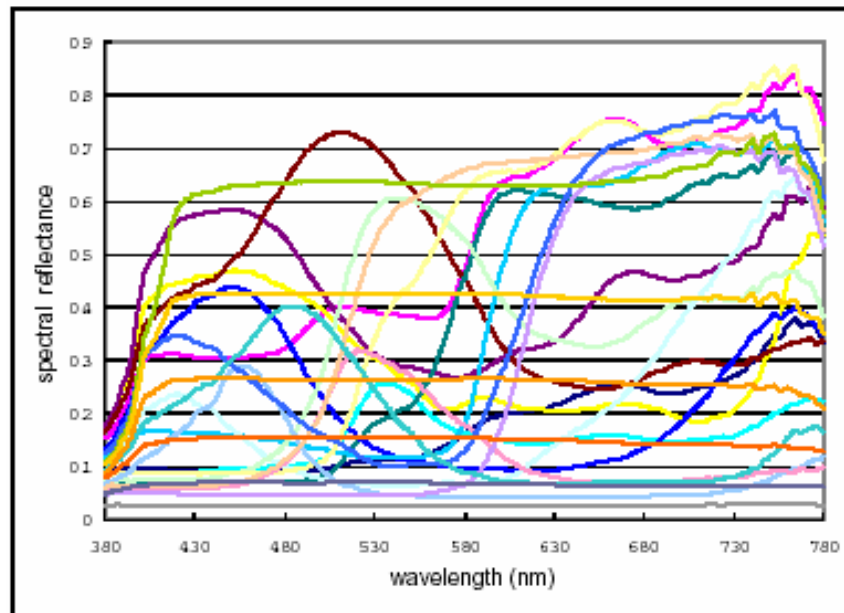


Fig. 6. Spectral reflectance of the objects.

– Three kinds of the illumination spectra

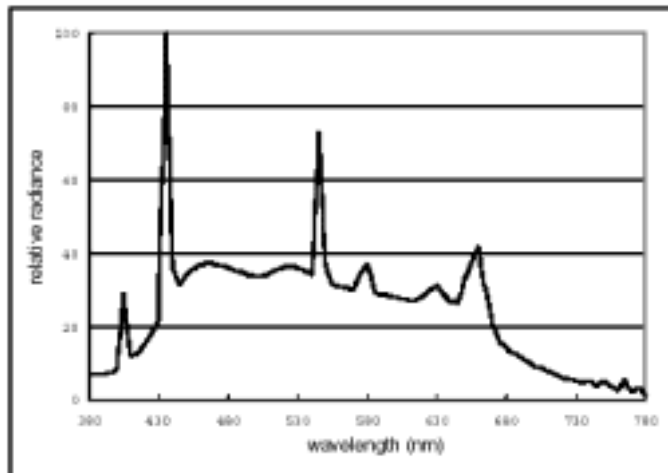


Fig. 7. Spectrum of the daylight.

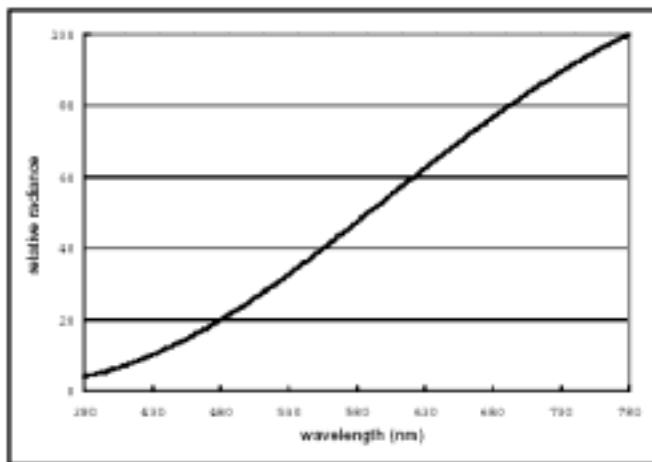


Fig. 8. Spectrum of the incandescent lamp.

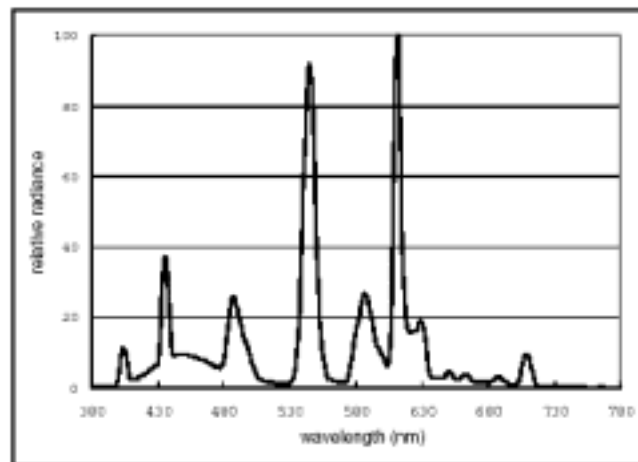


Fig. 9. Spectrum of the fluorescent lamp.



- The average and maximum error of the estimated colors

Table. 1. Color estimation errors in the simulation.

	Dav-Dav		Dav-A		Dav-EI	
	Ave	Max	Ave	Max	Ave	Max
6-band	0.57	1.97	0.74	2.64	0.84	2.52
3-band	2.60	8.70	1.91	7.70	2.78	9.42

	A-Dav		A-A		A-EI	
	Ave	Max	Ave	Max	Ave	Max
6-band	0.56	2.23	0.68	2.42	1.03	3.57
3-band	4.11	12.5	2.16	6.94	3.71	10.54

	EI-Dav		EI-A		EI-EI	
	Ave	Max	Ave	Max	Ave	Max
6-band	1.38	5.92	1.33	4.75	0.47	1.94
3-band	4.27	11.72	2.75	10.36	1.89	5.46

- ◆ Experiment result
  - Color estimation error

Table. 2. Color estimation errors in the experiment.

	Experiment		Simulation		Model Error	
	Ave	Max	Ave	Max	Ave	Max
6-band	1.43	4.24	0.72	2.82	1.09	2.96
3-band	4.12	8.22	1.07	4.33	3.83	9.59

# Discussion

## ◆ Distribution of the estimated color difference

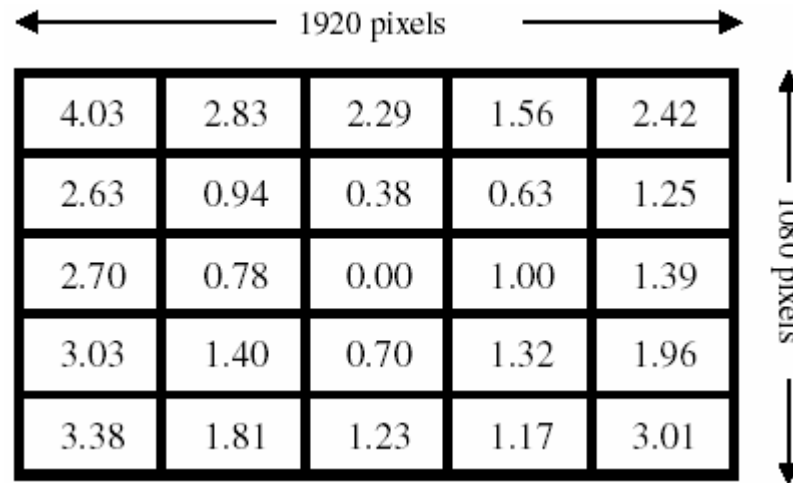


Fig. 10. Distribution of the estimated color difference relative to center of the image.

# ◆ Estimated color distribution in color plane

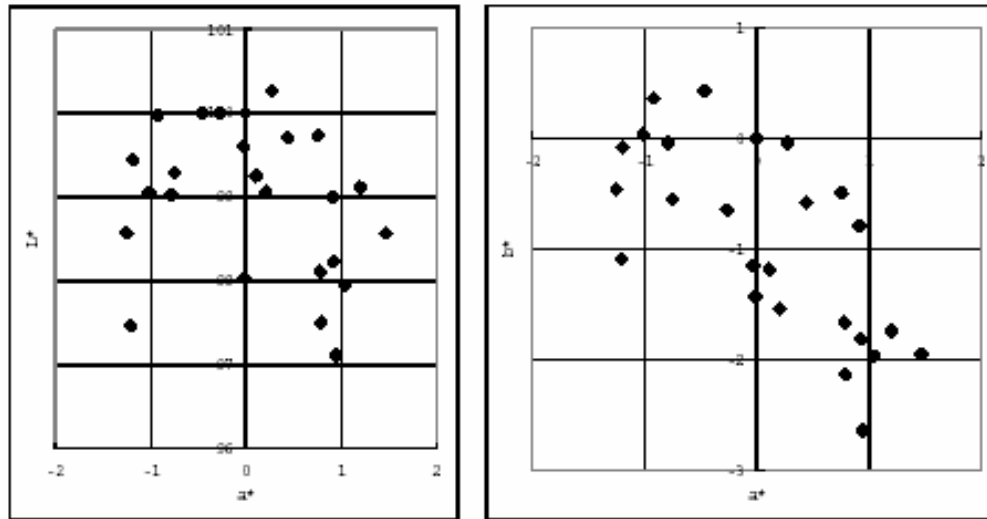


Fig. 11. Estimated color distribution in  $a^*-L^*$  and  $a^*-b^*$  plane.

# Conclusion

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- ◆ Comparing the accuracy of the estimated color
  - 6-band camera and conventional RGB HDTV camera
  - Confirming that 6-band camera is more accurate