Tunable Color Correction Between Linear and Polynomial Models For Noisy Images

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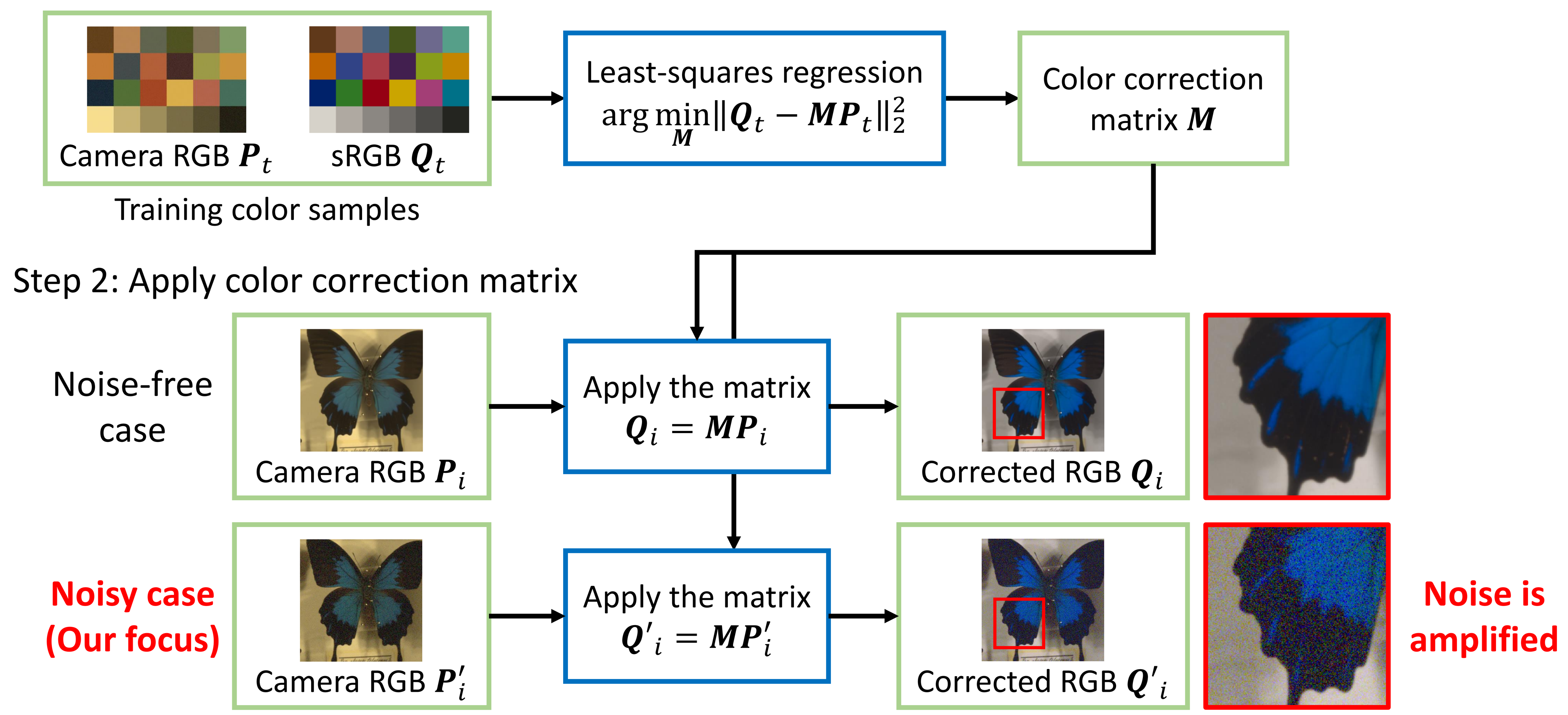
ICIP 2017
IEEE International Conference on Image Processing
September 17-20, 2017, Beijing, China
IEEE Signal Processing Society

Introduction: Color correction for noisy images

Color correction process



Linear color correction (LCC) [1]

$$q_{LCC} = M_{LCC} p_{LCC}$$

$$p_{LCC} = [1, p_r, p_g, p_b]^T$$

p_i: *Camera RGB value*

Polynomial color correction (PCC) [2]

$$q_{PCC} = M_{PCC} p_{PCC}$$

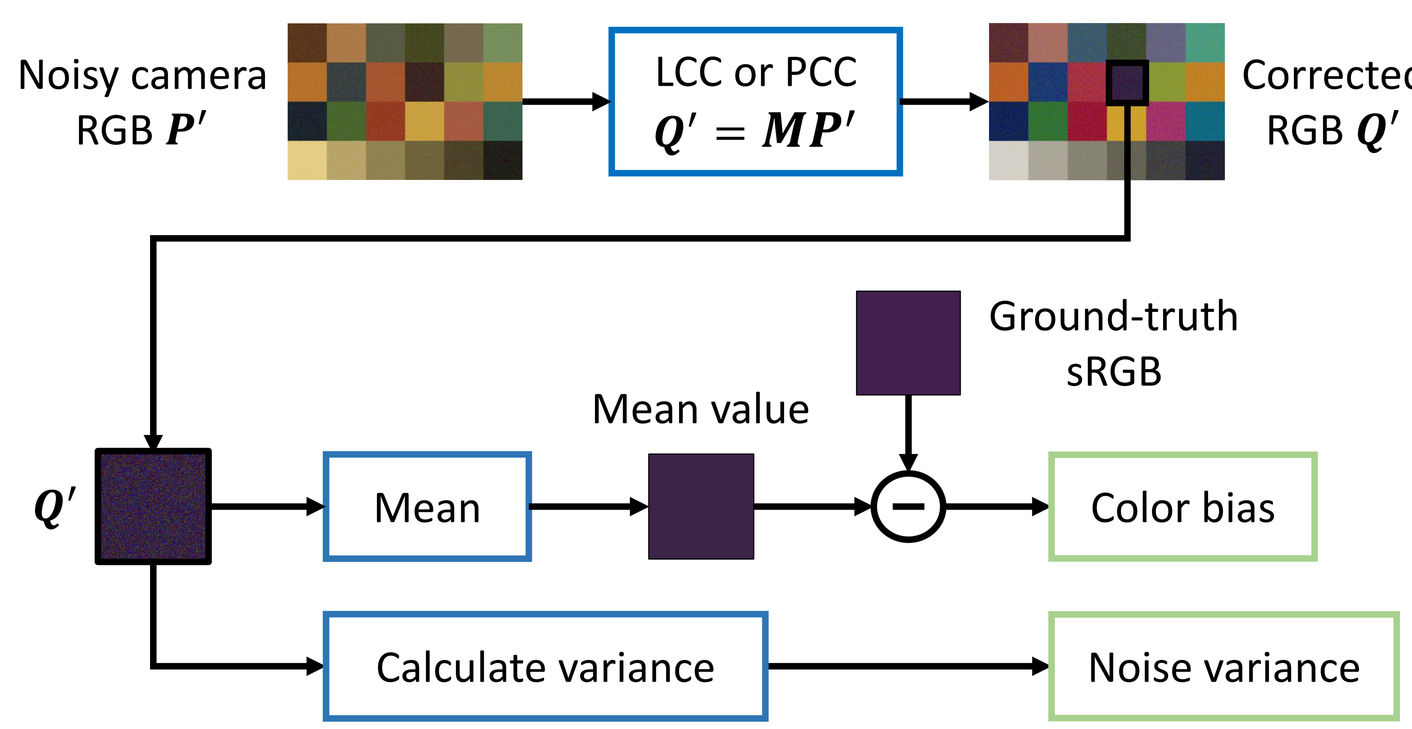
$$p_{PCC} = [1, p_r, p_g, p_b, p_{rg}, p_{gb}, p_{br}, p_{r^2}, p_{g^2}, p_{b^2}]^T$$

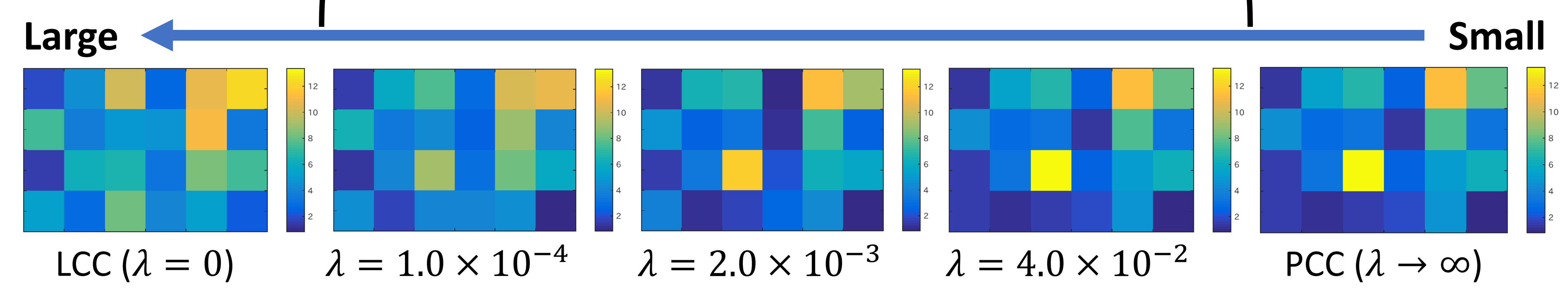
Use high-order terms (Our focus is 2nd-order PCC)

Proposed tunable color correction (TCC)

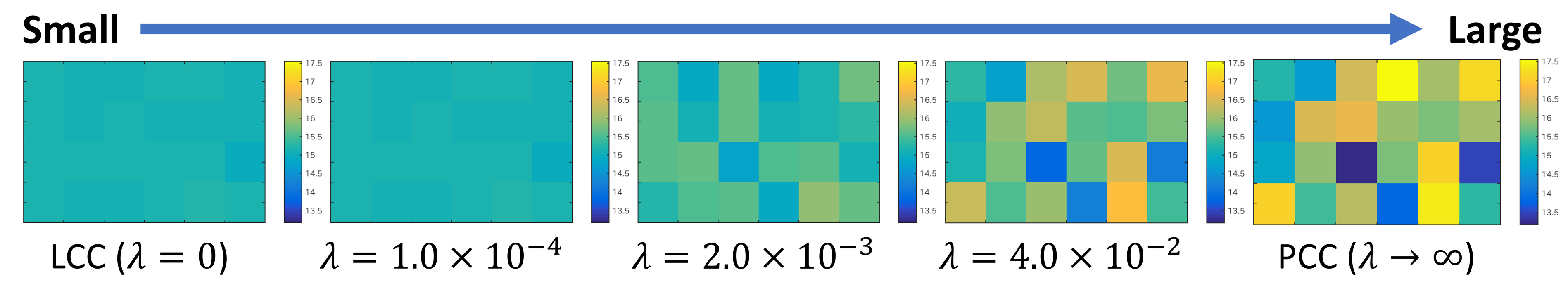
Tune the color correction matrix between LCC and PCC models and **optimize** the balance of the trade-off.

Color correction error analysis





Color bias



Noise standard deviation

Proposed tunable color correction (TCC)

Cost function of training matrix

$$\widehat{M}(\lambda) = \arg\min_M \left(\underbrace{\|Q_t - MP_t\|_F^2}_{\text{Data term}} + \underbrace{\frac{1}{\lambda}\|W \circ M\|_F^2}_{\text{Constraint term}} \right)$$

Element-wise product ($\circ$)

Key properties of TCC

$$\lim_{\lambda \to 0} \widehat{M}(\lambda) = [M_{lcc} \mid 0]$$

$$\lim_{\lambda \to \infty} \widehat{M}(\lambda) = M_{pcc}$$

Optimized matrix of TCC

$$M_{TCC} = \widehat{M}(\hat{\lambda})$$

$\hat{\lambda}$: *Optimized tuning parameter value*

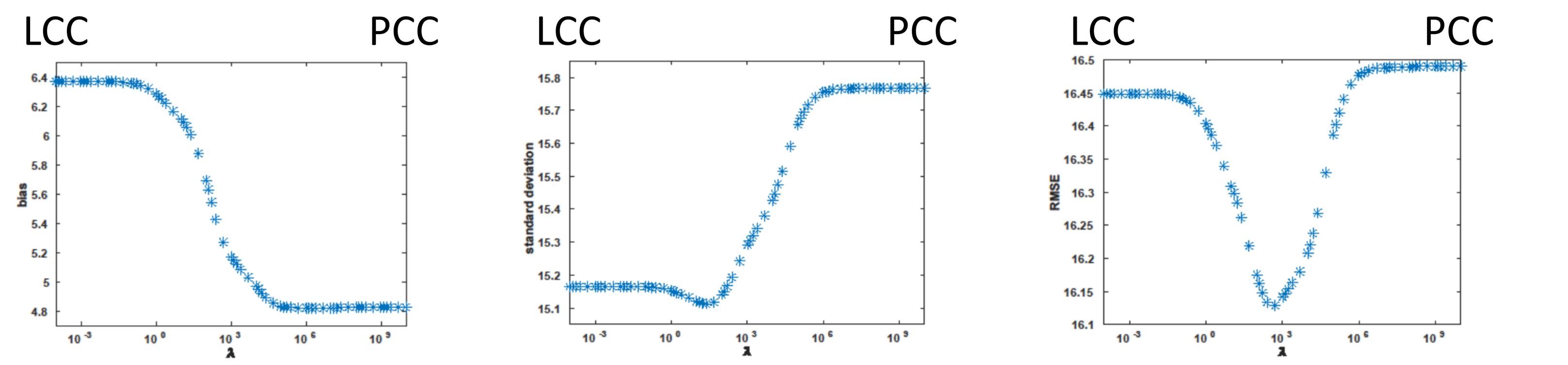
Data term

$$Q_t - MP_t = \begin{bmatrix} q_R & \cdots\cdots \\ q_G & \\ q_B & \end{bmatrix} - M_{3\times10} \begin{bmatrix} 1\ p_R\ p_G\ p_B\ p_{RG}\ p_{GB}\ p_{BR}\ p_R^2\ p_G^2\ p_B^2 \\ \vdots \\ \vdots \end{bmatrix}^T$$

Constraint term: Constraint on the 2nd-order terms of the matrix M.

$$W \circ M = \begin{bmatrix} 0\,0\,0\,0\,1\,1\,1\,1\,1\,1 \\ 0\,0\,0\,0\,1\,1\,1\,1\,1\,1 \\ 0\,0\,0\,0\,1\,1\,1\,1\,1\,1 \end{bmatrix} \circ \begin{bmatrix} 1\ m_{1,R}\ m_{1,G}\ m_{1,B}\ m_{1,RG}\ m_{1,GB}\ m_{1,BR}\ m_{1,R^2}\ m_{1,G^2}\ m_{1,B^2} \\ 1\ m_{2,R}\ m_{2,G}\ m_{2,B}\ m_{2,RG}\ m_{2,GB}\ m_{2,BR}\ m_{2,R^2}\ m_{2,G^2}\ m_{2,B^2} \\ 1\ m_{3,R}\ m_{3,G}\ m_{3,B}\ m_{3,RG}\ m_{3,GB}\ m_{3,BR}\ m_{3,R^2}\ m_{3,G^2}\ m_{3,B^2} \end{bmatrix}$$

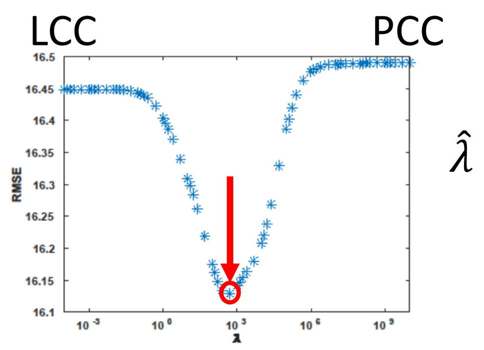
Simulation results with different parameter values for SG chart



Color bias | Noise standard deviation | RMSE

Optimize tuning parameter value

Find the optimal parameter value in terms of RMSE

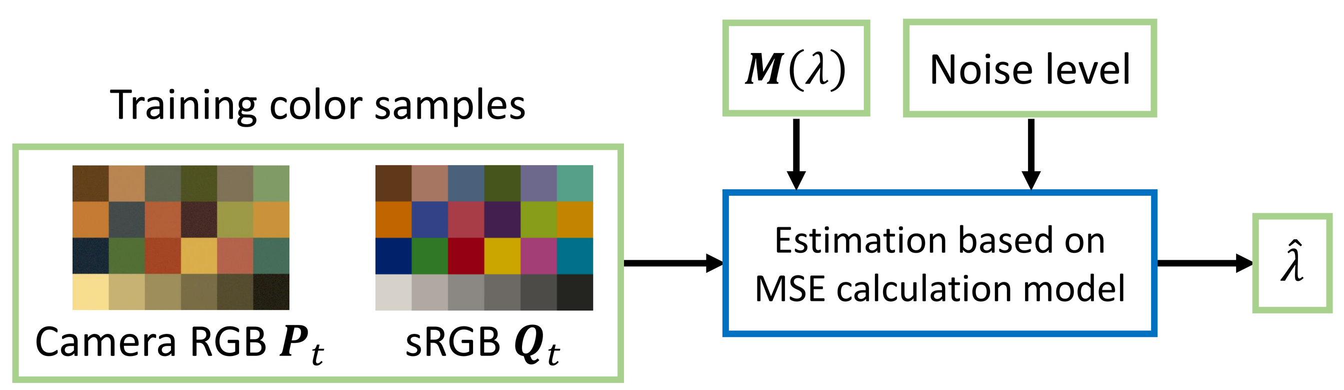


RMSE

$$\hat{\lambda} = \arg\min_{\lambda} MSE(\lambda)$$

$$= \arg\min_{\lambda}\left((color\ bias)^2 + (noise\ variance)\right)$$

The optimal value is calculated based on the MSE calculation model we derived (see the paper for details).



Experimental results

Setups

Training data: SG chart (96 patches)
Test data: SG chart (96 patches)
Hyperspectral images (30 scenes) [3]
Illumination: CIE A
Camera sensitivity: Olympus E-PL2 [4]

Numerical comparison: Average RMSE

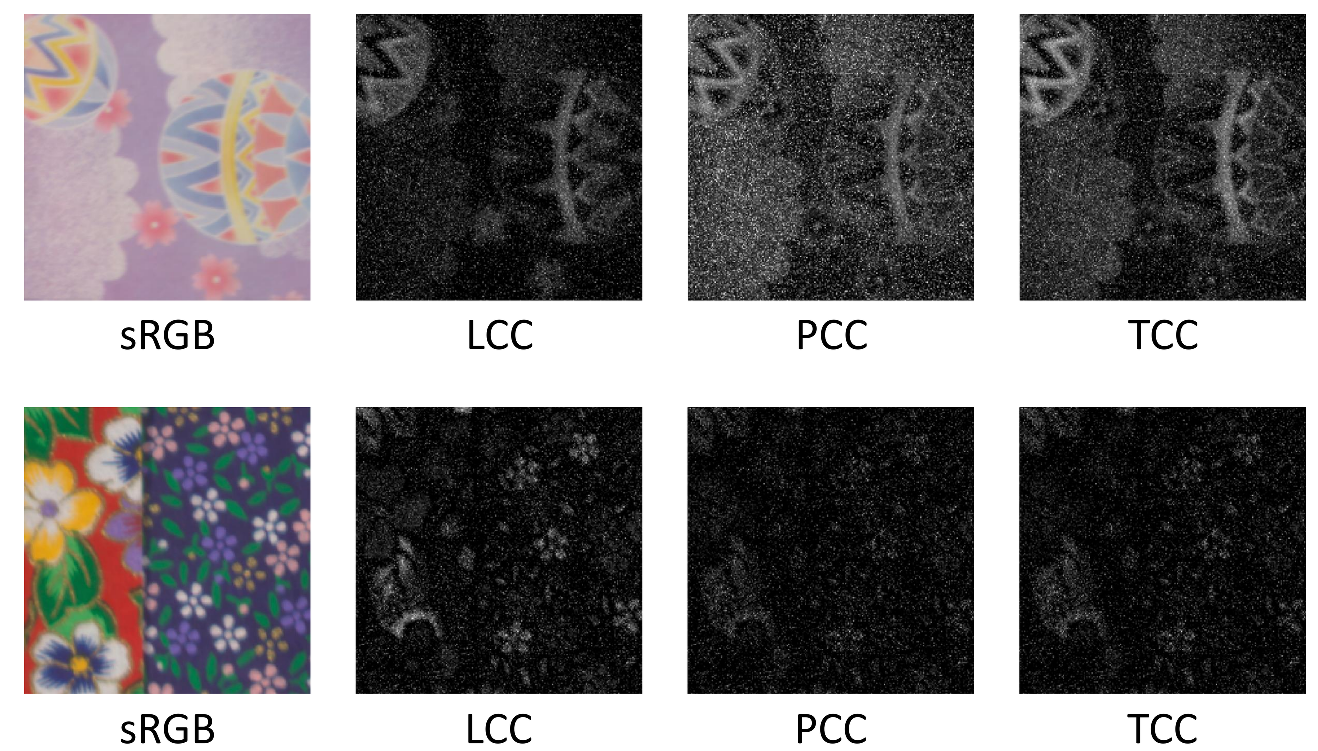
(Training data – Test data)

	SG chart - SG chart			SG chart - Hyperspectral		
σ	LCC	PCC	TCC	LCC	PCC	TCC
0	6.37	**4.81**	**4.81**	11.30	**10.65**	**10.65**
2	9.91	9.24	**9.17**	13.61	**13.24**	13.29
4	16.45	16.49	**16.13**	18.91	19.00	**18.83**
6	23.62	24.17	**23.41**	25.40	25.92	**25.32**
8	31.00	31.99	**30.81**	32.37	33.30	**32.25**
10	38.43	39.88	**38.23**	39.57	40.94	**39.44**

TCC can balance the trade-off between LCC and PCC.

Visual comparison for hyperspectral images:

RMSE map ($\sigma = 2$)



References

[1] P. M. Hubel, J. Holm, G. D. Finlayson, and M. S. Drew, "Matrix calculations for digital photography," Proc. of Color and Imaging Conference (CIC), pp. 105–111, 1997.
[2] G. Hong, M. R. Luo, and P. A. Rhodes, "A study of digital camera colorimetric characterisation based on polynomial modelling," Color Research and Application, vol. 26, no. 1, pp. 76–84, 2001.
[3] Y. Monno, S. Kikuchi, M. Tanaka, and M. Okutomi, "A practical one-shot multispectral imaging system using a single image sensor," IEEE Trans. on Image Processing, vol. 24, no. 10, pp. 3048–3059, 2015.
[4] J. Jiang, D. Liu, J. Gu, and S. Süsstrunk, "What is the space of spectral sensitivity functions for digital color cameras?," Proc. of Workshop on Applications of Computer Vision (WACV), pp. 168–179, 2013.