Supplementary Material

1 Statistics for different Benchmark datasets

1.1 SFU Laboratory dataset

	Recovery angular error				Reproduction angular error			
Method	P	σ	**Median**	Rank	P	σ	**Median**	Rank
Gray-World [2]	-	-	7.0°	11	-	-	7.49°	11
MaxRGB [10]	-	-	6.5°	10	-	-	7.44°	10
Shades-of-gray [5]	7	-	3.7°	**9**	7	-	3.94°	**8**
1st order gray-edge [14]	7	4	3.2°	**7**	14	4	3.59°	**6**
2nd order gray-edge [14]	14	10	2.7°	4	15	10	3.04°	4
Pixel-based gamut [6, 8]	-	4	2.267°	**2**	-	4	2.832°	**3**
Edge-based gamut	-	2	2.278°	**3**	-	2	2.697°	**2**
Intersection-based gamut	-	4	2.09°	1	-	3	2.48°	1
Union-based gamut	-	2	2.95°	5	-	2	3.38°	5
Heavy tailed-based [3]	-	-	3.45°	**8**	-	-	4.11°	**9**
Weighted gray-edge [7]	2	1	3.09°	**6**	2	1	3.62°	**7**

Table 1 : Recovery and Reproduction median errors of several colour constancy algorithms for SFU Lab dataset [1]. The ranks given to each algorithm are bold and underlined if they have changed. The optimal parameters are also shown where applicable and different ones are highlighted.

	Recovery angular error				Reproduction angular error			
Method	P	σ	**Mean**	Rank	P	σ	**Mean**	Rank
Gray-World	-	-	9.78°	11	-	-	10.08°	11
MaxRGB	-	-	9.09°	10	-	-	9.7°	10
Shades-of-gray	6	-	6.29°	8	6	-	6.8°	8
1st order gray-edge	1	1	6.89°	9	1	1	7.6°	9
2nd order gray-edge	6	5	5.15°	5	6	5	5.7°	5
Pixel-based gamut	-	4	3.7°	2	-	4	4.2°	2
Edge-based gamut	-	2	3.92°	3	-	2	4.5°	3
Intersection-based gamut	-	4	3.62°	1	-	4	4.1°	1
Union-based gamut	-	3	4.55°	4	-	3	5.1°	4
Heavy tailed-based	-	-	5.63°	7	-	-	6.2°	7
Weighted gray-edge	2	1	5.48°	6	2	1	6.1°	6

Table 2: Recovery and Reproduction mean errors of several colour constancy algorithms for SFU Lab dataset [1]. Not so many changes in ranking this selection of algorithms based on the mean errors, but still there existed local changes.

	Recovery angular error				Reproduction angular error			
Method	P	σ	**95% quantile**	Rank	P	σ	**95% quantile**	Rank
Gray-World	-	-	30.3°	11	-	-	27.99°	11
MaxRGB	-	-	27.3°	10	-	-	27.25°	10
Shades-of-gray	4	-	18.7°	**9**	3	-	18.92°	**8**
1st order gray-edge	2	1	14.3°	6	2	1	15.56°	6
2nd order gray-edge	2	2	14.2°	5	2	2	15.12°	5
Pixel-based gamut	-	6	9.8°	1	-	7	11.12°	1
Edge-based gamut	-	2	12.6°	**3**	-	2	14.35°	**4**
Intersection-based gamut	-	6	9.8°	2	-	7	11.2°	2
Union-based gamut	-	3	12.8°	**4**	-	3	13.2°	**3**
Heavy tailed-based	-	-	15.9°	7	-	-	16.6°	7
Weighted gray-edge	2	1	17.94°	**8**	2	1	19.3°	**9**

Table 3: Recovery and Reproduction 95% quantile errors of several colour constancy algorithms for SFU Lab dataset [1]. The ranks given to each algorithm are bold and underlined if they have changed. The optimal parameters are also shown where applicable and different ones are highlighted.

	Recovery angular error				Reproduction angular error			
Method	P	σ	**Trimean**[1]	Rank	P	σ	**Trimean**	Rank
Gray-World	-	-	7.6°	11	-	-	8.3°	11
MaxRGB	-	-	7.5°	10	-	-	8.2°	10
Shades-of-gray	6	-	4.5°	**9**	6	-	4.8°	**8**
1st order gray-edge	8	3	3.6°	**7**	8	3	4.1°	**6**
2nd order gray-edge	7	5	3.3°	4	7	5	3.6°	4
Pixel-based gamut	-	4	2.5°	2	-	2	3°	2
Edge-based gamut	-	2	2.7°	3	-	2	3.2°	3
Intersection-based gamut	-	4	2.4°	1	-	3	2.76°	1
Union-based gamut	-	3	3.4°	5	-	2	3.88°	5
Heavy tailed-based	-	-	4.3°	**8**	-	-	4.96°	**9**
Weighted gray-edge	2	1	3.6°	**6**	2	1	4.3°	**7**

Table 4 : Recovery and Reproduction trimean errors of several colour constancy algorithms for SFU Lab dataset [1]. The ranks given to each algorithm are bold and underlined if they have changed. The optimal parameters are also shown where applicable and different ones are highlighted.

[1] Trimean is defined as a weighted average of the data's median and its two quartiles.

1.2 Gray-ball dataset

	Recovery angular error				Reproduction angular error			
Method	P	σ	**Median**	Rank	P	σ	**Median**	Rank
Gray-World	-	-	6.97°	11	-	-	7.62°	11
MaxRGB	-	-	5.30°	**6**	-	-	5.52°	**5**
Shades-of-gray	8	-	5.28°	**5**	14	-	5.61°	**6**
1st order gray-edge	2	1	4.64°	3	2	1	4.8°	3
2nd order gray-edge	1	2	4.85°	4	1	2	5.1°	4
Pixel-based gamut	-	2	5.67°	**9**	-	2	5.9°	**8**
Edge-based gamut	-	1	5.62°	**8**	-	1	5.9°	**7**
Intersection-based gamut	-	6	5.7°	**10**	-	2	5.9°	**9**
Inverse intensity chromaticity space [13]	-	-	5.6°	**7**	-	-	6.1°	**10**
Using natural image statistics [15]	-	-	3.92°	2	-	-	4.3°	2
Exemplar-based colour constancy [9]	-	-	3.4°	1	-	-	3.7°	1

Table 5: Recovery and Reproduction median errors of several colour constancy algorithms for Gray-ball dataset [4]. The ranks given to each algorithm are bold and underlined if they have changed. The optimal parameters are also shown where applicable and different ones are highlighted.

	Recovery angular error				Reproduction angular error			
Method	P	σ	**Mean**	Rank	P	σ	**Mean**	Rank
Gray-World	-	-	7.87°	11	-	-	8.7°	11
MaxRGB	-	-	6.8°	7	-	-	7.1°	7
Shades-of-gray	9	-	6.11°	5	9	-	6.4°	5
1st order gray-edge	1	2	5.74°	3	1	2	6.1°	3
2nd order gray-edge	1	4	5.96°	4	1	4	6.3°	4
Pixel-based gamut	-	5	7.07°	10	-	5	7.3°	10
Edge-based gamut	-	3	6.82°	8	-	3	7.1°	8
Intersection-based gamut	-	8	6.9°	9	-	7	7.2°	9
Inverse intensity chromaticity space	-	-	6.6°	6	-	-	7.03°	6
Using natural image statistics	-	-	5.2°	2	-	-	5.48°	2
Exemplar-based colour constancy	-	-	4.4°	1	-	-	4.77°	1

Table 6: Recovery and Reproduction mean errors of several colour constancy algorithms for Gray-ball dataset [4]. Not so many changes in ranking this selection of algorithms based on the mean errors, but still there existed local changes.

	Recovery angular error				Reproduction angular error			
Method	P	σ	**95% quantile**	Rank	P	σ	**95% quantile**	Rank
Gray-World	-	-	17.8742°	11	-	-	20.8792°	11
MaxRGB	-	-	17.4402°	9	-	-	18.0055°	9
Shades-of-gray	9	-	13.8419°	**5**	8	-	14.5032°	**4**
1st order gray-edge	1	2	13.4586°	3	1	2	14.2717°	3
2nd order gray-edge	1	3	13.8398°	**4**	1	4	14.6954°	**5**
Pixel-based gamut	-	5	17.8235°	10	-	5	18.4689°	10
Edge-based gamut	-	3	16.1574°	7	-	4	16.6472°	7
Intersection-based gamut	-	9	16.1866°	8	-	8	16.9834°	8
Inverse intensity chromaticity space	-	-	15.2475°	6	-	-	15.9256°	6
Using natural image statistics	-	-	13.2190°	2	-	-	13.7330°	2
Exemplar-based colour constancy	-	-	11.3178°	1	-	-	12.4545°	1

Table 7: Recovery and Reproduction 95% quantile errors of several colour constancy algorithms for Gray-ball dataset [4]. The ranks given to each algorithm are bold and underlined if they have changed. The optimal parameters are also shown where applicable and different ones are highlighted.

	Recovery angular error				Reproduction angular error			
Method	P	σ	**Trimean**	Rank	P	σ	**Trimean**	Rank
Gray-World	-	-	7.1°	11	-	-	7.87°	11
MaxRGB	-	-	5.77°	**7**	-	-	5.99°	**6**
Shades-of-gray	8	-	5.48°	5	12	-	5.80°	5
1st order gray-edge	1	2	5.07°	3	2	1	5.38°	3
2nd order gray-edge	1	3	5.26°	4	1	3	5.55°	4
Pixel-based gamut	-	4	6.098°	10	-	3	6.32°	10
Edge-based gamut	-	2	6.027°	8	-	1	6.3180°	8
Intersection-based gamut	-	6	6.031°	9	-	6	6.3193°	9
Inverse intensity chromaticity space	-	-	5.8°	**6**	-	-	6.23°	**7**
Using natural image statistics	-	-	4.3°	2	-	-	4.67°	2
Exemplar-based colour constancy	-	-	3.67°	1	-	-	3.97°	1

Table 8: Recovery and Reproduction trimean errors of several colour constancy algorithms for Gray-ball dataset [4]. The ranks given to each algorithm are bold and underlined if they have changed. The optimal parameters are also shown where applicable and different ones are highlighted.

1.3 Colour-checker dataset (by Shi)

	Recovery angular error				Reproduction angular error			
Method	P	σ	**Median**	Rank	P	σ	**Median**	Rank
Gray-World	-	-	6.3°	17	-	-	6.8°	17
MaxRGB	-	-	5.7°	16	-	-	6.5°	16
Shades-of-gray	5	-	3.9°	12	5	-	4.4°	12
1st order gray-edge	3	3	4.3°	**13**	1	9	4.9°	**14**
2nd order gray-edge	3	6	4.4°	**14**	1	1	4.8°	**13**
Pixel-based gamut	-	4	2.3°	2	-	4	2.7°	2
Edge-based gamut	-	3	5.0°	15	-	3	5.8°	15
Intersection-based gamut	-	4	2.3°	3	-	4	2.7°	3
Regression (SVR)	-	-	6.73°	18	-	-	7.4°	18
Bayesian	-	-	3.46°	11	-	-	3.92°	11
Heavy tailed-based	-	-	2.96°	**8**	-	-	3.476°	**7**
Bottom-up	-	-	2.56°	5	-	-	3°	5
Top-down	-	-	2.63°	6	-	-	3.1°	6
Bottom-up+Top-down	-	-	2.47°	4	-	-	2.8°	4
Using Natural Image Statistics	-	-	3.13°	9	-	-	3.5°	9
CART-based Selection [12]	-	-	3.35°	10	-	-	3.90°	10
CART-based Combination	-	-	2.91°	**7**	-	-	3.479°	**8**
Exemplar-Based Color Constancy	-	-	2.27°	1	-	-	2.6°	1

Table 9: Recovery and Reproduction median errors of several colour constancy algorithms for Colour-checker (by Shi) dataset [11]. The ranks given to each algorithm are bold and underlined if they have changed. The optimal parameters are also shown where applicable and different ones are highlighted.

	Recovery angular error				Reproduction angular error			
Method	P	σ	**Mean**	Rank	P	σ	**Mean**	Rank
Gray-World	-	-	6.4°	15	-	-	7.1°	15
MaxRGB	-	-	7.5°	17	-	-	8.1°	17
Shades-of-gray	3	-	4.9°	**12**	3	-	5.5°	**11**
1st order gray-edge	1	9	5.3°	14	1	1	6.2°	14
2nd order gray-edge	1	1	5.1°	13	1	1	6.0°	13
Pixel-based gamut	-	5	4.1°	7	-	5	4.7°	7
Edge-based gamut	-	4	6.5°	16	-	4	7.8°	16
Intersection-based gamut	-	5	4.1°	8	-	5	4.7°	8
Regression (SVR)	-	-	8.08°	18	-	-	8.77°	18
Bayesian	-	-	4.82°	**11**	-	-	5.63°	**12**
Heavy tailed-based	-	-	3.67°	4	-	-	4.24°	4
Bottom-up	-	-	3.43°	2	-	-	3.98°	2
Top-down	-	-	3.75°	5	-	-	4.29°	5
Bottom-up+Top-down	-	-	3.48°	3	-	-	3.99°	3
Using Natural Image Statistics	-	-	4.19°	9	-	-	4.83°	9
CART-based Selection	-	-	4.49°	10	-	-	5.16°	10
CART-based Combination	-	-	3.9°	6	-	-	4.53°	6
Exemplar-Based Color Constancy	-	-	2.89°	1	-	-	3.4°	1

Table 10: Recovery and Reproduction mean errors of several colour constancy algorithms for Colour-checker (by Shi) dataset [11]. The ranks given to each algorithm are bold and underlined if they have changed. The optimal parameters are also shown where applicable and different ones are highlighted.

	Recovery angular error				Reproduction angular error			
Method	P	σ	**95% quantile**	Rank	P	σ	**95% quantile**	Rank
Gray-World	-	-	11.25°	**7**	-	-	12.41°	**6**
MaxRGB	-	-	19.01°	18	-	-	20.05°	18
Shades-of-gray	2	-	10.56°	5	2	-	11.97°	5
1st order gray-edge	1	1	11.33°	**8**	1	1	14.56°	**11**
2nd order gray-edge	1	1	11.01°	**6**	1	1	13.66°	**9**
Pixel-based gamut	-	5	13.60°	14	-	5	15.44°	14
Edge-based gamut	-	5	16.1°	**16**	-	5	19.93°	**17**
Intersection-based gamut	-	5	13.6°	15	-	5	15.47°	15
Regression (SVR)	-	-	17.25°	**17**	-	-	18.89°	**16**
Bayesian	-	-	12.60°	13	-	-	15.39°	13
Heavy tailed-based	-	-	8.68°	2	-	-	9.89°	2
Bottom-up	-	-	9.53°	**3**	-	-	11.57°	**4**
Top-down	-	-	12.13°	**11**	-	-	13.81°	**10**
Bottom-up+Top-down	-	-	11.55°	**9**	-	-	13.59°	**8**
Using Natural Image Statistics	-	-	11.69°	**10**	-	-	12.95°	**7**
CART-based Selection	-	-	12.49°	12	-	-	14.63°	12
CART-based Combination	-	-	10.14°	**4**	-	-	11.43°	**3**
Exemplar-Based Color Constancy	-	-	6.95°	1	-	-	8.32°	1

Table 11 : Recovery and Reproduction 95% quantile errors of several colour constancy algorithms for Colour- checker (by Shi) dataset [11]. The ranks given to each algorithm are bold and underlined if they have changed. The optimal parameters are also shown where applicable and different ones are highlighted

	Recovery angular error				Reproduction angular error			
Method	P	σ	**Trimean**	Rank	P	σ	**Trimean**	Rank
Gray-World	-	-	6.3°	16	-	-	6.9°	16
MaxRGB	-	-	6.4°	17	-	-	7.1°	17
Shades-of-gray	4	-	4.2°	**11**	4	-	4.8°	**12**
1st order gray-edge	2	6	4.7°	14	1	6	5.3°	14
2nd order gray-edge	1	1	4.6°	13	1	1	5.2°	13
Pixel-based gamut	-	4	2.9°	5	-	4	3.4°	5
Edge-based gamut	-	4	5.4°	15	-	4	6.5°	15
Intersection-based gamut	-	4	2.9°	6	-	4	3.4°	6
Regression (SVR)	-	-	7.19°	18	-	-	7.92°	18
Bayesian	-	-	4.36°	**12**	-	-	4.36°	**11**
Heavy tailed-based	-	-	3.11°	7	-	-	3.62°	7
Bottom-up	-	-	2.72°	3	-	-	3.15°	3
Top-down	-	-	2.81°	4	-	-	3.25°	4
Bottom-up+Top-down	-	-	2.61°	2	-	-	2.94°	2
Using Natural Image Statistics	-	-	3.45°	9	-	-	3.94°	9
CART-based Selection	-	-	3.55°	10	-	-	4.14°	10
CART-based Combination	-	-	3.23°	8	-	-	3.75°	8
Exemplar-Based Color Constancy	-	-	2.42°	1	-	-	2.87°	1

Table 12 : Recovery and Reproduction trimean errors of several colour constancy algorithms for Colour-checker (by Shi) dataset [11]. The ranks given to each algorithm are bold and underlined if they have changed. The optimal parameters are also shown where applicable and different ones are highlighted.

2 Visualization of the worst case angular error

Suppose we image a scene under a white illuminant (the correct = $[1\ 1\ 1]^t$). Now we estimate the illuminate using some algorithm as $[R\ G\ B]^t$. The angle between $[R\ G\ B]^t$ and $[1\ 1\ 1]^t$ is the recovery error. If we take a picture of the same scene under a second illuminant $[\alpha, \beta, \gamma]^t$ then, according to the RGB model of image formation, the estimated illuminant will be $[\alpha *R, \beta *G, \gamma *B]^t$ (almost always illuminant estimation algorithm will return an estimate that is biased according to the same scaling factors). Now the recovery angular error is between the vectors $[\alpha, \beta, \gamma]^t$ and $[\alpha *R, \beta *G, \gamma *B]^t$. Following from the recovery error theorem in the paper we can solve for the illuminant which, over all possible lights, induces the maximum recovery. To visualize these 'most challenging' lights we can colour the point in the *rg* chromaticity diagram (r=R/(R+G+B) and g=G/(R+G+B)) with the colour of the worst case illuminant. This is shown in Figure 1.

The left of the figure, (A) shows the chromaticity of the initial RGB estimate (assuming the correct answer is r=1/3 and g=1/3). In the same location of the chromaticity diagram in the right panel, (B), we show the colour of the worst case light (given the initial estimate at the same location in the left panel)

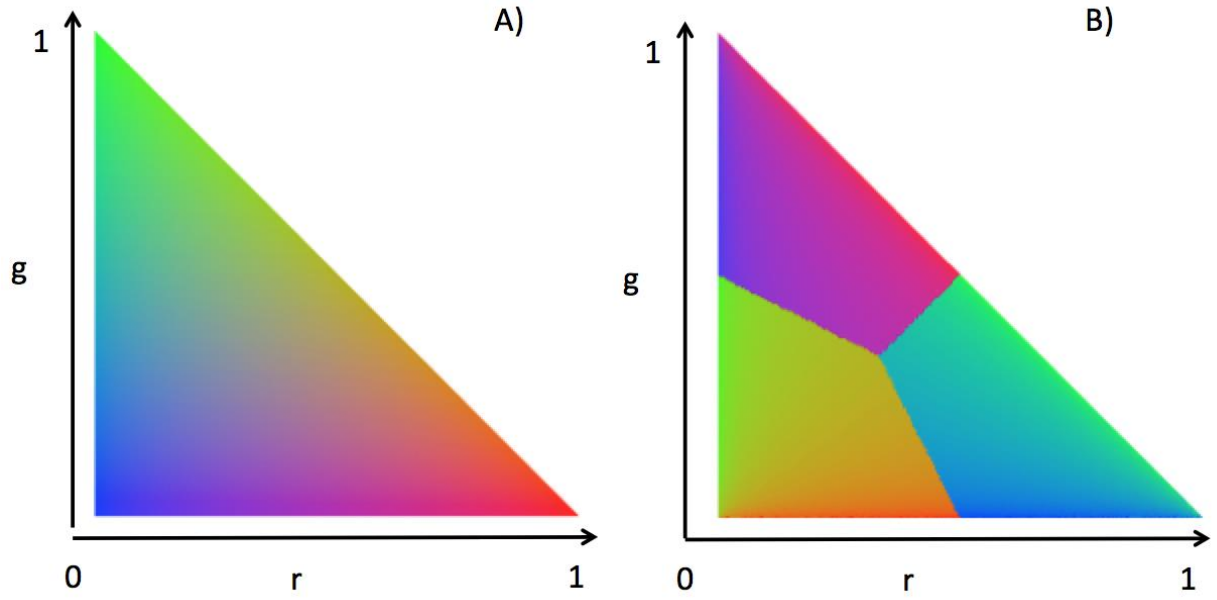

Figure 1: Left panel: chromaticities of putative illuminant estimates for a scene where the correct illuminant estimate is r=1/3 and g=1/3 (white light). Right panel: given the initial wrong answer, the worst case light (the light under which a given illuminant estimation algorithm will perform worst for a given scene) is calculated.

References

[1] Kobus Barnard, Lindsay Martin, Brian Funt, and Adam Coath. A data set for color research. Color Research & Application, 27(3):147–151, 2002.

[2] Gershon Buchsbaum. A spatial processor model for object colour perception. Journal of the Franklin institute, 310(1):1–26, 1980.

[3] Ayan Chakrabarti, Keigo Hirakawa, and Todd Zickler. Color constancy with spatiospectral statistics. IEEE Transactions on Pattern Analysis and Machine Intelligence, 34(8):1509–1519, 2012.

[4] Florian Ciurea and Brian Funt. A large image database for color constancy research. 11th IS & T/SID Color and Imaging Conference, 2003(1):160–164, 2003.

[5] Graham D Finlayson and Elisabetta Trezzi. Shades of gray and colour constancy. 12th IS & T/SID Color and Imaging Conference, 2004(1):37–41, 2004.

[6] David A Forsyth. A novel algorithm for color constancy. International Journal of Computer Vision, 5(1):5–36, 1990.

[7] Arjan Gijsenij, Theo Gevers, and Joost Van De Weijer. Improving color constancy by photometric edge weighting. IEEE Transactions on Pattern Analysis and Machine Intelligence, 34(5):918–929, 2012.

[8] Arjan Gijsenij, Theo Gevers, and Joost Van DeWeijer. Generalized gamut mapping using image derivative structures for color constancy. International Journal of Computer Vision, 86(2-3):127–139, 2010.

[9] Joze, H. R. V., & Drew, M. S. (2012). Exemplar-Based Colour Constancy. In BMVC (pp. 1-12).

[10] Edwin Herbert Land et al. The retinex theory of color vision. Scientific American, 237 (6):108–128, 1977.

[11] Lilong Shi and Brian Funt. Re-processed version of the gehler color constancy dataset of 568 images. Simon Fraser University, 2010. URL http://www.cs.sfu.ca/~colour/data/.

[12] Bianco, S., Ciocca, G., & Cusano, C. (2009). Color constancy algorithm selection using CART. In Computational Color Imaging (pp. 31-40). Springer Berlin Heidelberg.

[13] Robby T Tan, Ko Nishino, and Katsushi Ikeuchi. Color constancy through inverseintensity chromaticity space. Journal of the Optical Society of America A, 21(3):321–334, 2004.

[14] Joost Van De Weijer, Theo Gevers, and Arjan Gijsenij. Edge-based color constancy. IEEE Transactions on Image Processing, 16(9):2207–2214, 2007.

[15] Van De Weijer, J., Schmid, C., & Verbeek, J. (2007, October). Using high-level visual information for color constancy. In *Computer Vision, 2007. ICCV 2007. IEEE 11th International Conference on* (pp. 1-8). IEEE.