Supplemental Document

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ZCAM, a colour appearance model based on a high dynamic range uniform colour space: supplement

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ZCAM, a colour appearance model based on a high dynamic range uniform colour space: supplemental document

This supplemental document presents equation of the inverse ZCAM and a few working examples for implementation of ZCAM.

1. THE INVERSE ZCAM MODEL

This section gives equation of the inverse ZCAM colour appearance model developed based on a uniform colour space [1]. The surround factor (F_s), the background factor (F_b), and the luminance level adaptation factor (F_L) are computed in the same way as in the forward model. Three ZCAM attributes (Q_z or J_z, M_z or C_z or W_z or K_z or S_z or V_z, and h_z or H_z) and corresponding reference white should be given to compute tristimulus values ($[X_{D65},\ Y_{D65},\ Z_{D65}]$) of the sample.

- **Step 1:** If Q_z or J_z is given then I_z can be obtained by using Eq. (S1) or (S2), respectively.

$$I_z = \left(\frac{Q_z}{2700 \cdot (F_s)^{2.2} \cdot (F_b)^{0.5} \cdot (F_L)^{0.2}} \right)^{\frac{(F_b)^{0.12}}{1.6 \cdot F_s}}. \tag{S1}$$

$$I_z = \left(\frac{J_z \cdot Q_{z,w}}{2700 \cdot 100 \cdot (F_s)^{2.2} \cdot (F_b)^{0.5} \cdot (F_L)^{0.2}} \right)^{\frac{(F_b)^{0.12}}{1.6 \cdot F_s}}. \tag{S2}$$

- **Step 2:** If C_z and M_z are not given, then C_z can be obtained from one of S_z, V_z, K_z, or W_z using Eqs. (S3–S6), respectively.

$$C_z = \left(\frac{Q_z \cdot (S_z)^2}{100 \cdot Q_{z,w} \cdot (F_L)^{1.2}} \right). \tag{S3}$$

$$C_z = \sqrt{\frac{(V_z)^2 - (J_z - 58)^2}{3.4}}. \tag{S4}$$

$$C_z = \sqrt{\frac{1}{8}\left(\left(\frac{100 - K_z}{0.8} \right)^2 - (J_z)^2 \right)}. \tag{S5}$$

$$C_z = \sqrt{(100 - W_z)^2 - (100 - J_z)^2}. \tag{S6}$$

- **Step 3:** If H_z is given, h_z(degrees) can be calculated by using data in Table 1 in the forward model, choosing a proper i ($i = 1,\ 2,$ or 3) so that $H_i \leq H < H_{i+1}$. Then computing h' using

$$h' = \frac{(H - H_i) \cdot (e_{i+1} \cdot h_i - e_i \cdot h_{i+1}) - 100 \cdot e_{i+1} \cdot h_i}{(H - H_i) \cdot (e_{i+1} - e_i) - 100 \cdot e_{i+1}}, \tag{S7}$$

  and then set $h_z = h' - 360^{o}$ if $h' > 360^{o}$, otherwise, $h_z = h'$.

- **Step 4:** Calculate a_z and b_z using Eqs. (S8) and (S9), respectively.

$$a_z = C'_z \cdot cos\left(h_z \cdot \frac{\pi}{180} \right), \tag{S8}$$

$$b_z = C'_z \cdot sin\left(h_z \cdot \frac{\pi}{180} \right), \tag{S9}$$

  where,

$$C'_z = \sqrt{a_z^2 + b_z^2} = \left(\frac{M_z \cdot (I_{z,w})^{0.78} \cdot (F_b)^{0.1}}{100 \cdot (e_z)^{0.068} \cdot (F_L)^{0.2}} \right)^{1.3514}, \tag{S10}$$

where, e_z can be computed in the same way as in the forward model and M_z can obtained using

$$M_z = \frac{C_z \cdot Q_{z,w}}{100}. \tag{S11}$$

- **Step 5:** Once values of I_z, a_z, and b_z are obtained from Steps 1–4, use following equations to obtain tristimulus values ($[X_{D65}, Y_{D65}, Z_{D65}]$).

$$I = I_z + \epsilon. \tag{S12}$$

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 3.524000 & -4.066708 & 0.542708 \\ 0.199076 & 1.096799 & -1.295875 \end{bmatrix}^{-1} \begin{bmatrix} I \\ a_z \\ b_z \end{bmatrix}. \tag{S13}$$

$$\{R,\ G,\ B\} = 10,000 \left(\frac{c_1 - (\{R',\ G',\ B'\})^{\frac{1}{\rho}}}{c_3 \cdot (\{R',\ G',\ B'\})^{\frac{1}{\rho}} - c_2} \right)^{\frac{1}{\eta}}. \tag{S14}$$

$$\begin{bmatrix} X'_{D65} \\ Y'_{D65} \\ Z_{D65} \end{bmatrix} = \begin{bmatrix} 0.41478972 & 0.579999 & 0.0146480 \\ -0.2015100 & 1.120649 & 0.0531008 \\ -0.0166008 & 0.264800 & 0.6684799 \end{bmatrix}^{-1} \begin{bmatrix} R \\ G \\ B \end{bmatrix}. \tag{S15}$$

$$X_{D65} = \frac{1}{b} \cdot (X_{D65'} + (b-1) \cdot Z_{D65}). \tag{S16}$$

$$Y_{D65} = \frac{1}{g} \cdot (Y_{D65'} + (g-1) \cdot X_{D65}). \tag{S17}$$

Values of constants ϵ, c_1, c_2, c_3, ρ, η, b, and g, are given in the forward model.

2. WORKING EXAMPLES FOR ZCAM

Five working examples for ZCAM are listed in Table S1. Note that tristimulus values of sample and the reference white are absolute (i.e., in units of cd/m^2).

Table S1. Working examples for ZCAM.

No.		1	2	3	4	5
Sample	X	185	89	79	910	96
	Y	206	96	81	1114	67
	Z	163	120	62	500	28
Reference White	X	256	256	256	2103	2103
	Y	264	264	264	2259	2259
	Z	202	202	202	1401	1401
Surround		average	average	dim	dark	dark
L_a		264	264	150	359	359
Y_b		100	100	60	16	16
F_L		1.0970	1.0970	1.0970	1.2153	1.2153
F_b		0.6155	0.6155	0.6155	0.0842	0.0842
I_z		0.3947	0.3163	0.2913	0.6190	0.2749
a_z		-0.0165	-0.0166	0.0018	-0.0320	0.0765
b_z		-0.0048	-0.0472	0.0029	0.0475	0.0437
h_z		196.3524	250.6422	58.7532	123.9464	389.7720
H_z		237.6401	307.0595	43.8258	178.6422	397.3301
Q_z		321.3464	248.0394	196.7686	114.7431	45.8363
J_z		92.2520	71.2071	68.8890	82.6445	33.0139
M_z		10.5252	23.8744	2.7918	18.1655	26.9446
C_z		3.0216	6.8539	0.9774	13.0838	19.4070
S_z		19.1314	32.7963	12.5916	44.7277	86.1882
V_z		34.7022	18.2796	11.0371	34.4874	43.6447
K_z		25.2994	40.4621	44.4143	26.8778	47.9942
W_z		91.6837	70.4026	68.8737	78.2653	30.2593

REFERENCES

1. M. Safdar, G. Cui, Y. J. Kim, and M. R. Luo, "Perceptually uniform color space for image signals including high dynamic range and wide gamut," Opt. Express **25**, 15131–15151 (2017).