Full-Reference Image Quality Expression via Genetic Programming

Supplementary Material

Illya Bakurov, Marco Buzzelli, Raimondo Schettini, Mauro Castelli, and Leonardo Vanneschi

I. Assessment of elite individuals

TABLE I
CROSS-DATASET ASSESSMENT OF ELITE INDIVIDUALS AT THE LAST GENERATION OPTIMIZED ON KADID10K. FOR EACH COMBINATION OF TERMINAL SET AND DATASET, WE REPORT PLCC STATISTICS (MAXIMUM, AVERAGE AND STANDARD DEVIATION), AS WELL AS THE SSIM-EQUIVALENT THAT CAN BE OBTAINED FROM THE CORRESPONDING TERMINAL SET.

PLCC

	TID2008				TID2013				LIVE2				LIVEM			
	SSIM'	MAX	AVG	STD	SSIM'	MAX	AVG	STD	SSIM'	MAX	AVG	STD	SSIM'	MAX	AVG	STD
T_L	0.467	0.718	0.542	0.130	0.564	0.754	0.517	0.187	0.459	0.874	0.691	0.161	0.650	0.794	0.693	0.091
T_L (MMM)	0.467	0.746	0.530	0.166	0.564	0.735	0.502	0.227	0.459	0.866	0.602	0.199	0.650	0.794	0.673	0.106
T_{M_A}	0.443	0.808	0.678	0.138	0.446	0.792	0.632	0.181	0.633	0.896	0.708	0.124	0.390	0.871	0.789	0.055
T_{M_A} (MMM)	0.443	0.798	0.565	0.200	0.446	0.792	0.473	0.235	0.633	0.908	0.524	0.248	0.390	0.875	0.737	0.136
T_{M_S}	0.720	0.793	0.678	0.125	0.735	0.764	0.562	0.190	0.668	0.865	0.699	0.102	0.756	0.872	0.795	0.054
T_{M_S} (MMM)	0.720	0.779	0.596	0.181	0.735	0.769	0.444	0.243	0.668	0.846	0.558	0.204	0.756	0.854	0.773	0.087
$T_{H_{SS}}$	0.747	0.847	0.764	0.075	0.766	0.842	0.742	0.093	0.749	0.881	0.758	0.121	0.800	0.857	0.786	0.053
$T_{H_{SS}}$ (MMM)	0.747	0.852	0.795	0.049	0.766	0.846	0.791	0.049	0.749	0.891	0.737	0.121	0.800	0.876	0.799	0.068
$T_{H_{MS}}$	0.793	0.858	0.753	0.072	0.781	0.843	0.729	0.076	0.687	0.903	0.832	0.060	0.795	0.871	0.750	0.080
$T_{H_{MS}}$ (MMM)	0.793	0.859	0.788	0.044	0.781	0.844	0.766	0.047	0.687	0.899	0.694	0.115	0.795	0.888	0.796	0.037

	VDID2014				CSIQ				PieAPP			
	SSIM'	MAX	AVG	STD	SSIM'	MAX	AVG	STD	SSIM'	MAX	AVG	STD
T_L	0.755	0.898	0.735	0.130	0.317	0.826	0.602	0.159	0.030	0.310	0.151	0.089
T_L (MMM)	0.755	0.897	0.660	0.217	0.317	0.811	0.519	0.216	0.030	0.316	0.142	0.107
T_{M_A}	0.611	0.860	0.693	0.138	0.381	0.842	0.691	0.096	0.136	0.367	0.185	0.106
T_{M_A} (MMM)	0.611	0.896	0.639	0.211	0.381	0.909	0.557	0.220	0.136	0.288	0.149	0.078
T_{M_S}	0.745	0.780	0.589	0.144	0.710	0.913	0.688	0.089	0.133	0.327	0.133	0.087
T_{M_S} (MMM)	0.745	0.802	0.630	0.113	0.710	0.794	0.556	0.198	0.133	0.301	0.129	0.067
$T_{H_{SS}}$	0.734	0.896	0.814	0.082	0.796	0.889	0.819	0.058	0.236	0.308	0.212	0.062
$T_{H_{SS}}$ (MMM)	0.734	0.901	0.793	0.093	0.796	0.896	0.807	0.062	0.236	0.363	0.251	0.051
$T_{H_{MS}}$	0.736	0.921	0.857	0.039	0.778	0.892	0.808	0.074	0.010	0.415	0.289	0.124
$T_{H_{MS}}$ (MMM)	0.736	0.914	0.809	0.051	0.778	0.928	0.819	0.055	0.010	0.419	0.104	0.108

II. Selected individuals

$$\text{GP-SSIM } T_L = \frac{\mathrm{G}(X)\left(\mathrm{G}(Y)^{0.05}\right)^{20.0}\mathrm{G}(Y)^{1.25}\left(\mathrm{G}\left(XY\right)^{2.0} - \mathrm{G}\left(X^2\right)\mathrm{G}\left(Y^2\right)\right)^{2.0}}{\mathrm{G}\left(XY\right)^4\left(-\mathrm{G}\left(Y^2\right) + 2\,\mathrm{G}\left(XY\right) - \mathrm{G}\left(X^2\right)\right)} \tag{1}$$

$$\text{GP-SSIM } T_{M_A} = \frac{\frac{\frac{2\sigma_{\mathrm{xy}}}{\max({\sigma_x}^2, {\sigma_y}^2)\left(({\mu_x}^2+\sigma_y)^{0.5}\right)^{0.3}+{\sigma_x}^2} + \frac{|\sigma_{\mathrm{xy}}|^{32.0}}{|\sigma_x|^{32.0}|\sigma_y|^{32.0}}}{2} + \frac{\sigma_y}{\max({\sigma_x}^2, {\sigma_y}^2)}}{2} \tag{2}$$

$$\text{GP-SSIM } T_{M_S}\text{-A} = \frac{{\sigma_y}^2 + {\sigma_x}^2}{\sigma_{xy}} - \left(\frac{\left({\sigma_y}^2 - \sigma_x\sigma_y + {\sigma_x}^2\right)^{0.05} + \sigma_{xy}}{{\sigma_y}^2 - \sigma_x\sigma_y + {\sigma_x}^2}\right)^{11.11} \tag{3}$$

$$\text{GP-SSIM } T_{M_S}\text{-B} = \frac{\left({\sigma_y}^2 + {\sigma_x}^2\right)^{1.25}}{|\sigma_{xy}|^{2.5}} - \frac{{\sigma_y}^2 + {\sigma_x}^2}{\sigma_{xy}} \tag{4}$$

$$\begin{aligned}\text{GP-SSIM } T_{H_{SS}}\text{-A} = \Big(\left(s^{133.2} + c^{256.0}\right)^{1.0} + \left(c^{2.0}\, l^{0.1}\, s^{2.0} - l^{8.0}\right)^{2.0} + \left(l^{8884.44} + c^{6.67}\right)^{0.5} \\ + \left(l^{444.222} + c^{6.67}\right)^{0.25}\Big)\ \Big(\left(s^{426.24} + c^{256.0}\right)^{1.0} + s^{3.2}\Big)\end{aligned} \tag{5}$$

$$\begin{aligned}\text{GP-SSIM } T_{H_{SS}}\text{-B} = s^{0.6} + 0.5\Big(\max\left(c^{1.25}, l^{39.0625}, \min\left(l^{6.67}, 0.5\,(s+l)\right)\right) \\ + \max\Big(c, 0.0098\left(l^{40.0} + c^{0.05}\right)^{6.67}, s^{0.8}, s, 0.5\left(0.5\,(ls+l) + l^{6.67}\right)\Big)^{66.6}\Big)\end{aligned} \tag{6}$$

$$\begin{aligned}\text{GP-SSIM } T_{H_{MS}}\text{-A} = \left(\left({c_3}^{2.0}\left(l_4 + {c_3}^{2.0}\right) - {s_3}^{40.0}\right)\left(\left({c_3}^{2.0}\left(s_4 + l_5\right) - {s_2}^{6.66}\right)\left(s_5 + s_4 + s_2\right) - {s_4}^{0.1}\right)\right. \\ \left. - {s_3}^{40.0}\right)\left({s_2}^{400.0}{s_5}^{400.0} + {c_2}^{133.2}\right)^{1.25} + \left({s_2}^{6.0}{s_4}^{20.0}{s_5}^{26.0} + {s_2}^{20.0}{s_5}^{20.0}\right)^{2.0} + {s_3}^{20.0}\end{aligned} \tag{7}$$

$$\begin{aligned}&\text{GP-SSIM } T_{H_{MS}}\text{-B} \\ &= \max\left(\begin{array}{c}\left(0.7071\left({s_3}^{1.25} + \max\left(c_2, \dfrac{\frac{\left(s_2 + \max\left({c_4}^{20.0}, \frac{s_3+s_2}{2}\right)\right){s_5}^{0.8}}{2} + \frac{{c_4}^{0.25}}{{c_1}^{0.25}}}{2}\right)\right)^{0.5}, \\ \dfrac{\left(\dfrac{\max\left({c_3}^{3.33}, {s_3}^{1.25}\right)^{6.67} c_4 \min(c_5, s_2){s_5}^{2.0}}{c_1} + \max\left(c_2 \max\left({c_4}^{20.0}, c_2 l_4\right), {s_2}^{0.5}{s_5}^{0.5}\right)^{20.0}\right)^{2.0} + \left(l_1 - c_4\right)^{3.33}}{2}\end{array}\right)\end{aligned} \tag{8}$$

III. Performance per distortion type / per dataset

TABLE II
PERFORMANCE PER DISTORTION TYPE OF GP-SSIM $T_{H_{MS}}$-B. TID2008 DATASET.

TID2008		
Type	PLCC	SRCC
Additive Gaussian noise	0.753	0.763
Additive noise in color	0.754	0.752
Spatially correlated noise	0.582	0.816
High frequency noise	0.892	0.875
Quantization noise	0.800	0.867
Gaussian blur	0.910	0.962
JPEG compression	0.930	0.925
JPEG2000 compression	0.871	0.969
JPEG transmission errors	0.875	0.880
JPEG2000 transmission errors	0.707	0.848
Mean shift (intensity shift)	0.506	0.481
Contrast change	0.501	0.480
Masked noise	0.469	0.615
Impulse noise	0.542	0.657
Image denoising	0.818	0.952
Non eccentricity pattern noise	0.799	0.800
Local block-wise distortions of different intensity	0.550	0.813

TABLE III
PERFORMANCE PER DISTORTION TYPE OF GP-SSIM $T_{H_{MS}}$-B. TID2013 DATASET.

TID2013		
Type	PLCC	SRCC
Additive Gaussian noise	0.842	0.837
Additive noise in color	0.761	0.769
Spatially correlated noise	0.733	0.844
Masked noise	0.506	0.613
High frequency noise	0.909	0.867
Impulse noise	0.709	0.741
Quantization noise	0.832	0.873
Gaussian blur	0.935	0.969
Image denoising	0.848	0.921
JPEG compression	0.942	0.915
JPEG2000 compression	0.907	0.949
JPEG transmission errors	0.893	0.844
JPEG2000 transmission errors	0.815	0.885
Non eccentricity pattern noise	0.842	0.823
Local block-wise distortions of different intensity	0.281	0.538
Mean shift (intensity shift)	0.500	0.604
Contrast change	0.469	0.334
Change of color saturation	0.076	0.118
Multiplicative Gaussian noise	0.778	0.776
Comfort noise	0.915	0.887
Lossy compression of noisy images	0.875	0.919
Image color quantization with dither	0.863	0.877
Chromatic aberrations	0.911	0.871
Sparse sampling and reconstruction	0.881	0.953

TABLE IV
PERFORMANCE PER DISTORTION TYPE OF GP-SSIM $T_{H_{MS}}$-B. LIVE2 DATASET.

LIVE2		
Type	PLCC	SRCC
jp2k	0.943	0.958
jpeg	0.919	0.904
wn	0.922	0.980
gblur	0.903	0.969
fastfading	0.904	0.944

TABLE V
PERFORMANCE PER DISTORTION TYPE OF GP-SSIM $T_{H_{MS}}$-B. LIVEM DATASET.

LIVEM		
Type	PLCC	SRCC
blur	0.424	0.788
blur jpeg	0.526	0.735
jpeg	0.717	0.649
blur noise	0.597	0.772
noise	0.895	0.878

TABLE VI
PERFORMANCE PER DISTORTION TYPE OF GP-SSIM $T_{H_{MS}}$-B. CSIQ DATASET.

CSIQ		
Type	PLCC	SRCC
awgn	0.923	0.938
jpeg	0.968	0.959
jpeg2000	0.947	0.969
fnoise	0.899	0.922
blur	0.934	0.978
contrast	0.923	0.943

TABLE VII
PERFORMANCE PER DISTORTION TYPE OF GP-SSIM $T_{H_{MS}}$-B. PIEAPP DATASET.

PieAPP		
Type	PLCC	SRCC
deblurtikanov motion	0.751	0.785
deblurchan gaussian	0.871	0.861
swirltransform	0.343	0.334
superres zeyde	0.773	0.914
globalimshiftrotateradial	0.396	0.456
softfocus	0.722	0.892
superressrcnn	0.930	0.876
superrespeleg	0.636	0.610
comfortnoise	0.690	0.692
deblurchan motion	0.758	0.780
stretchtransform horizontal	0.459	0.593
spatiallyvaryingnoise denoiser	0.725	0.787
histogran equalization	0.124	0.109
wavetransform	0.182	0.239
denoiserof sb gaussian	0.091	0.095
vignette effect	0.692	0.650
gaussiannoiseadditive	0.786	0.846
stretchtransform vertical	0.387	0.613
compressivesensing danielyan	0.836	0.865
changecolortemp	0.838	0.750
deblurdenoisechan gaussian gaussian	0.813	0.851
gaussianhighfrequencynoise	0.612	0.533
jpeg2000compression	0.844	0.862
specklenoise	0.399	0.500
denoisebm3d gaussian	0.718	0.762
superres aplus	0.577	0.500
polytransform	0.285	0.357
deblurtikanov gaussian	0.946	0.900
poissonnoise	0.615	0.727
deblurdenoisechan motion gaussian	0.794	0.882
logtransform	0.704	0.582