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A comparative study of perceptual quality and aesthetic attributes across Tone-Mapping Operators.

Motivation

Tone-mapping operators (TMOs) are algorithms designed to convert high-dynamic range (HDR) images into perceptually similar low-dynamic range (LDR) images. In this study, we designed three psychophysical experiments to evaluate the performance of nine TMOs. These experiments allowed us to compare the digitally-generated tone-mapped images to each other; and **these tone-mapped images against the real HDR scene**. Our results enabled **the construction of three rankings**: (i) evaluating grayscale and the conservation of intrinsic properties, (ii) faithfulness to reality, and (iii) aesthetic appeal.

Methods

Participants

The three tasks were completed by 13 participants (54% female), aged between 16 and 50 y.o. with normal or corrected-to-normal vision. All of them were completely naïve to the experiment's purpose.

TMOs

Initially, we considered 60 different TMOs. However, to avoid including improved or deprecated algorithms, we settled for those published after 2017, and whose source code was available online. Following this criteria, eight TMOs were selected (see references). An extra TMO (directly available from an OPPO Find X3 Neo -model CPH2207- mobile phone) was also included, totalling 9 TMOs.

Experimental setup

- We created 2 *dioramas* including objects of different colours and shapes. They were illuminated with a high intensity light (6500K, 100W incandescent bulb) from 2 sides totalling 4 different test scenes.

- A calibrated set of 32 grey squares was presented in the background, fully illuminated (they appeared linearly increasing in lightness to the eye). They were labelled as a grid (A1, A2, A3, B1, B2, … etc.)
- Test objects (rectangular boxes) were placed inside illuminated and shaded areas. Their sides were made from grey squares samples.
- Images of real scenes were taken with a calibrated camera and processed by the tested TMOs. They were presented on a calibrated LCD monitor.
- Both the real scene and the monitor were placed side by side. The position and viewing angle of the images was chosen so that they appeared the same as the real scene to the observer. A dark screen was placed to stop light from the test scene reaching the monitor.

Experiment 1: Segment Matching

Observers matched the lightness of the visible faces of the test objects to the patches of the reference grey squares (N = 23 faces in total)

Experiment 2: Scene Reproduction

Observers rated the tone-mapped images according to their fidelity to the real scene in a 10-point Likert scale. They were advised to focus on details such as shadows, colour preservation, sharpness, over/under exposition and overall sensation of realism

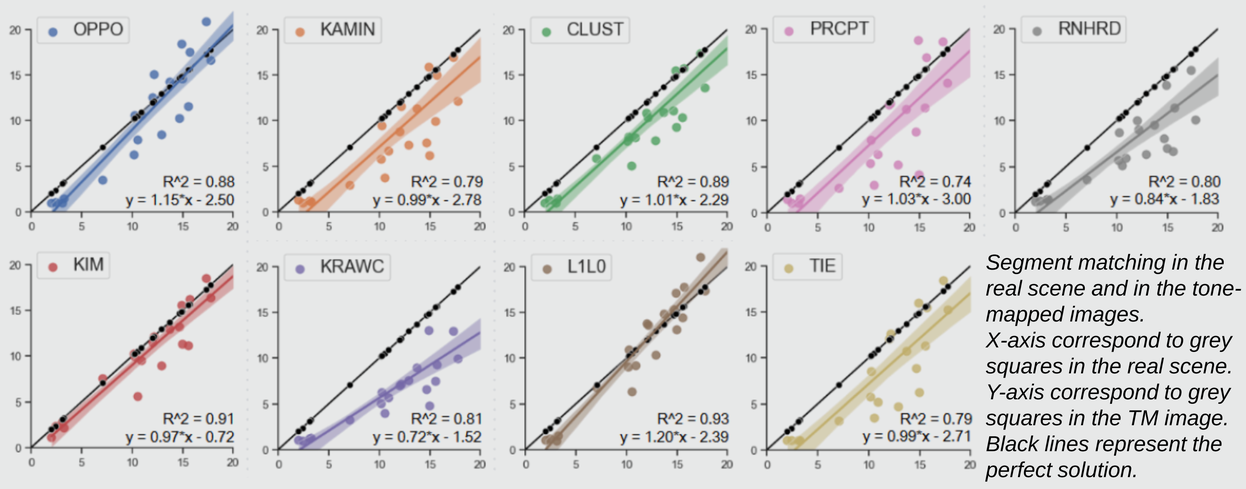
Experiment 3: Aesthetics

Observers rated the overall aesthetics of the tone-mapped images in a 10-point Likert scale)

Design of the Segment Matching Experiment.

Results

Experiment 1: Segment Matching

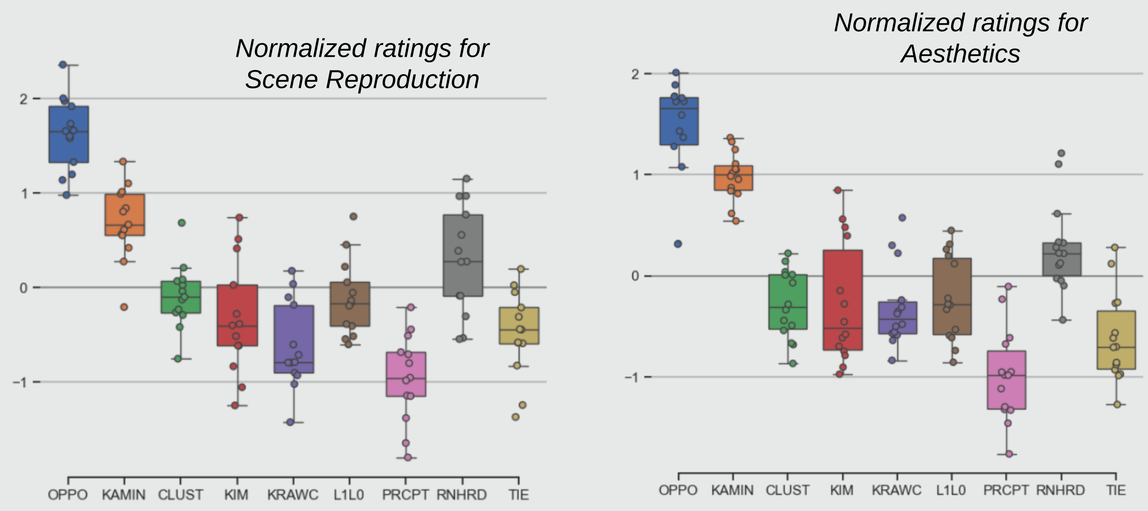


Segment matching in the real scene and in the tone-mapped images. X-axis correspond to grey squares in the real scene. Y-axis correspond to grey squares in the TM image. Black lines represent the perfect solution.

TMO	Slope Difference	RMSE	T-test p-value	R^2	Type
OppoCPH2207	0.149	2.600	0.726	0.880	Modern
Kaminari	**0.012**	4.074	0.108	0.792	Modern
Li2018	**0.011**	2.927	0.225	0.890	Modern
KimKautz	0.027	**2.058**	0.541	0.905	Classic
Krawczyk	0.283	5.613	**0.002**	0.807	Classic
Liang	0.200	**2.122**	0.969	0.933	Modern
Khan2020	0.029	4.315	0.163	0.741	Modern
Reinhard	0.159	4.562	**0.025**	0.797	Classic
Khan2018	**0.011**	4.050	0.117	0.788	Classic

Summary of linear regression models. The lower the slope difference and the RMSE, the better

Experiments 2 and 3: Scene Reproduction and Aesthetics



Conclusions

On the one hand, in recent years, tone-mapping operators have significantly improved in terms of perceptual quality. Their results, particularly in scene reproduction and aesthetics, suggest that developers have prioritized these aspects. On the other hand, classical tone-mapping operators do preserve local relationships between objects, which does not appear to strongly affect scene reproduction or aesthetics.

Nonetheless, there is still considerable room for further perceptual enhancements in tone-mapping operators.

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