High Dynamic Range Image Tone Mapping By Optimizing Tone Mapped Image Quality Index

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Outline

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Advantage and Acquisition

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Represent higher precision of luminance levels in natural scenes.

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The Acquisition of HDR Images

- Directly acquired with HDR imaging devices;
- Indirectly fused from multiple Low Dynamic Range (LDR) images captured at different exposure levels.

Tone Mapping Operators (TMO)

Objective

Compress the dynamic range of HDR images for display on LDR devices.

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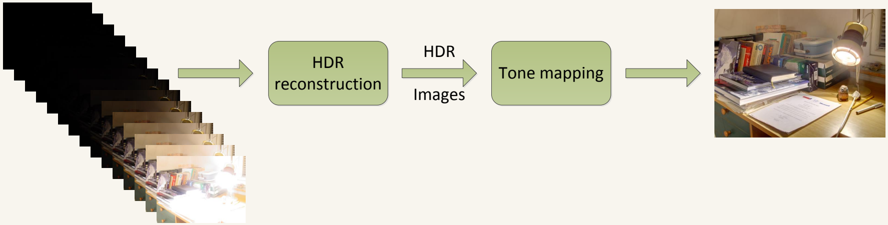
Why TMOs?

- A surrogate for HDR display technology;
- Show HDR images on printed media;
- An interesting problem by itself.

The Workflow

HDR Imaging Workflow



Existing TMOs

Literature Review

- Linear, Gamma and Log-normal mappings;
- Stevens's law-based algorithm [Tumblin, 1993];
- Histogram adjustment technique [Larson, 1997];
- Gradient-based algorithm [Fattal, 2002];
- Photographic tone mapping [Reinhard, 2002];
- Adaptive logarithmic mapping [Drago, 2003];
- Display adaptive tone mapping [Mantiuk, 2008];
- Linear windowed tone mapping [Shan, 2010];
- Multiscale decomposition based algorithm [Gu, 2013].

A Visual Example

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- Which algorithm is the best?

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- Which algorithm is the best?
- Any room for further improvement? If any, how?

Quality Assessment of Tone Mapped Images

Subjective Quality Assessment

- Expensive;
- Time consuming;
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Objective Quality Assessment

- Traditional quality measures do not apply.
- Tone mapped image quality index (TMQI).

TMQI

TMQI Computation in [Yeganeh, 2013]

Two key factors: structural fidelity and statistical naturalness.

$$\mathrm{TMQI} = \mathrm{a}\mathrm{S}(\mathbf{X}, \mathbf{Y})^{\alpha} + (1 - \mathrm{a})\mathrm{N}(\mathbf{Y})^{\beta}\,. \tag{1}$$

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Structural fidelity:

$$S_{\mathrm{local}}(\mathbf{x}, \mathbf{y}) = \frac{2\tilde{\sigma}_x\tilde{\sigma}_y + C_1}{\tilde{\sigma}_x^2 + \tilde{\sigma}_y^2 + C_1} \cdot \frac{\sigma_{xy} + C_2}{\sigma_x\sigma_y + C_2} , \tag{2}$$

Statistical naturalness:

$$N = \frac{1}{K} P_m P_d . \tag{3}$$

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TMQI Optimization

Mathematical Formulation

$$\mathbf{Y}_{\text{opt}} = \arg\max_{\mathbf{Y}} \text{TMQI}(\mathbf{X}, \mathbf{Y}) \,. \tag{4}$$

Structural Fidelity Update

$$\hat{\mathbf{Y}}_k = \mathbf{Y}_k + \lambda \nabla_{\mathbf{Y}} S(\mathbf{X}, \mathbf{Y})|_{\mathbf{Y}=\mathbf{Y}_k} \,. \tag{5}$$

Statistical Naturalness Update

$$y^i_{k+1} = \begin{cases} (3/L)a\hat{y}^i_k & 0 \le \hat{y}^i_k \le L/3 \\ (3/L)(b-a)\hat{y}^i_k + (2a-b) & L/3 < \hat{y}^i_k \le 2L/3 \\ (3/L)(L-b)\hat{y}^i_k + (3b-2L) & 2L/3 < \hat{y}^i_k \le L \end{cases} \,. \tag{6}$$

Structural Fidelity Update Only

Tone-mapped “Desk” Images and Their Structural Fidelity Maps

(a) initial image (b) after 10 iterations (c) after 50 iterations (d) after 100 iterations (e) after 200 iterations

(f) initial image, S = 0.689 (g) 10 iterations, S = 0.921 (h) 50 iterations, S = 0.954 (i) 100 iterations, S = 0.961 (j) 200 iterations, S = 0.966

Statistical Naturalness Update Only

Tone-mapped “Building” Images

(a) initial image, N = 0.000 (b) 10 iterations, N = 0.001 (c) 50 iterations, N = 0.428 (d) 100 iterations, N = 0.868 (e) 200 iterations, N = 0.971

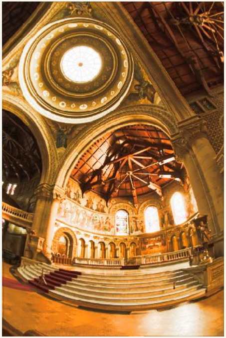
TMQI comparison between initial and converged images

Image		Gamma	Reinhard's	Drago's	Log-normal
Bridge	initial image	0.8093	0.9232	0.8848	0.7439
	converged image	0.9928	0.9929	0.9938	0.9944
Lamp	initial image	0.5006	0.9387	0.8717	0.7371
	converged image	0.9906	0.9925	0.9910	0.9894
Memorial	initial image	0.4482	0.9138	0.8685	0.7815
	converged image	0.9895	0.9894	0.9868	0.9867
Woman	initial image	0.6764	0.8891	0.8918	0.8026
	converged image	0.9941	0.9947	0.9943	0.9937

Full version of the proposed algorithm

Tone-mapped Images Created by Gamma Mapping

(a) S=0.148, N=0.000



(b) S=0.959, N=0.997

(c) S=0.521, N=0.038

(d) S=0.976, N=0.999

Full version of the proposed algorithm Cont.1

Tone-mapped “Bridge” Images Created by [Reinhard, 2002]

(a) S=0.847, N=0.764

(b) S=0.971, N=1.000

Full version of the proposed algorithm Cont.2

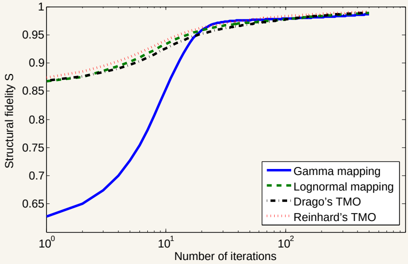
Tone-mapped “Lamp” Images Created by [Drago, 2003]

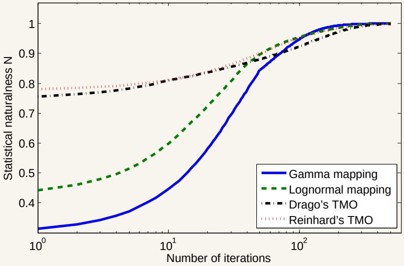
(a) S=0.787, N=0.966

(b) S=0.970, N=0.999

Numerical Analysis

Evolution of Tone-mapped Image “Woods” with Initial Images Created by Different TMOs.





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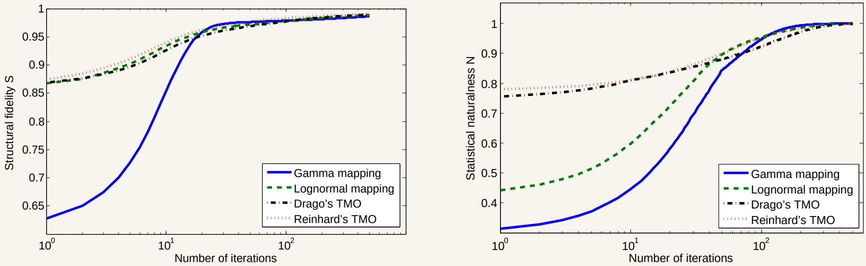

- Increase monotonically;

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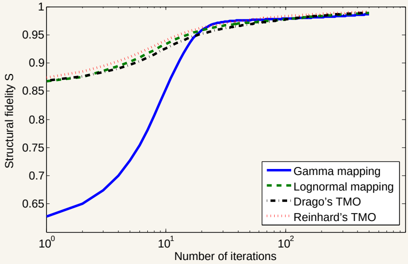

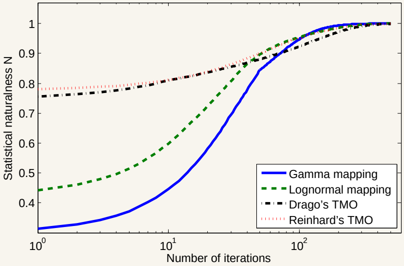

- Increase monotonically;
- Converge regardless of initial images;

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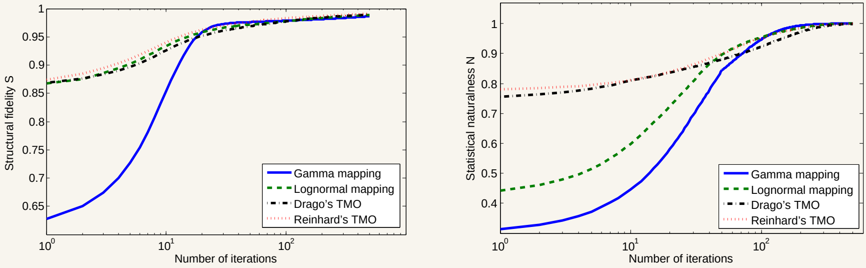

- Increase monotonically;
- Converge regardless of initial images;
- Trapped in local optima.

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Conclusions

Contribution

- Proposed an iterative tone mapping algorithm by optimizing TMQI;

Future work

- Develop better quality measures;
- Classify and quantify distortions introduced by TMOs;
- Improve the optimization process.

References

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Thank you