Color Enhancement with Adaptive Illumination Estimation for Low Backlighted Displays

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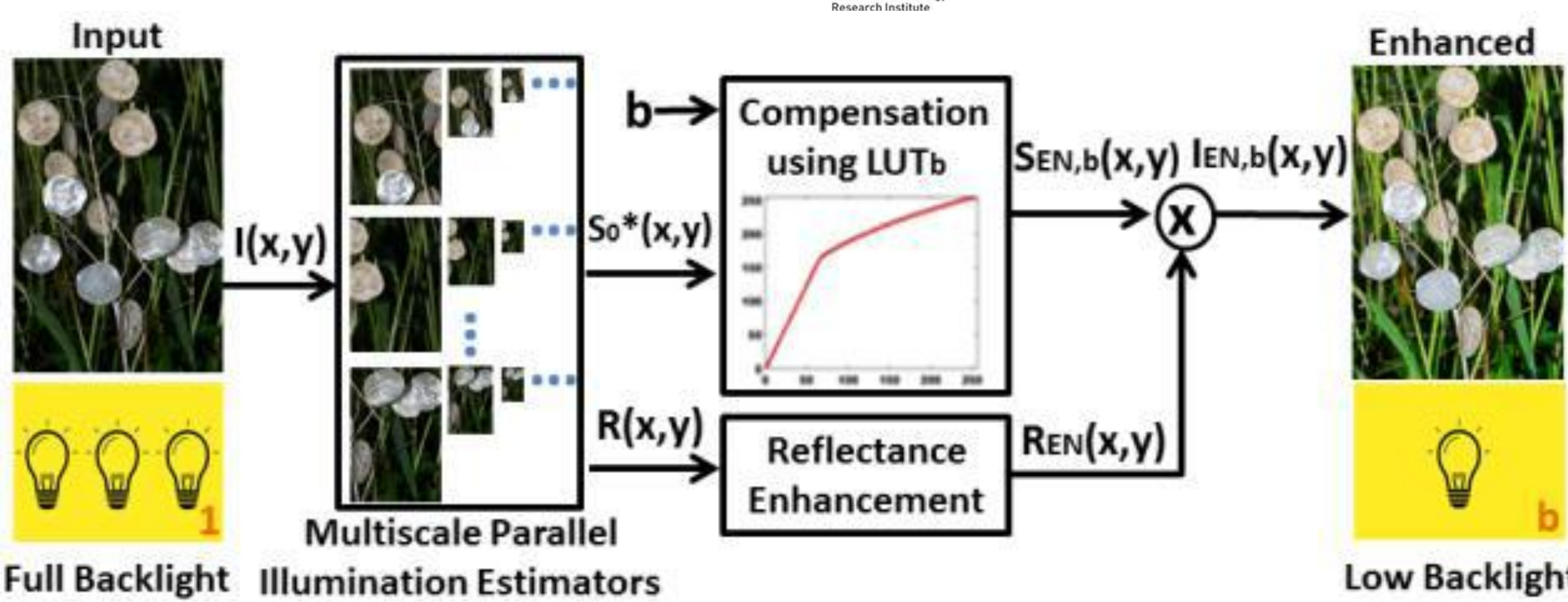
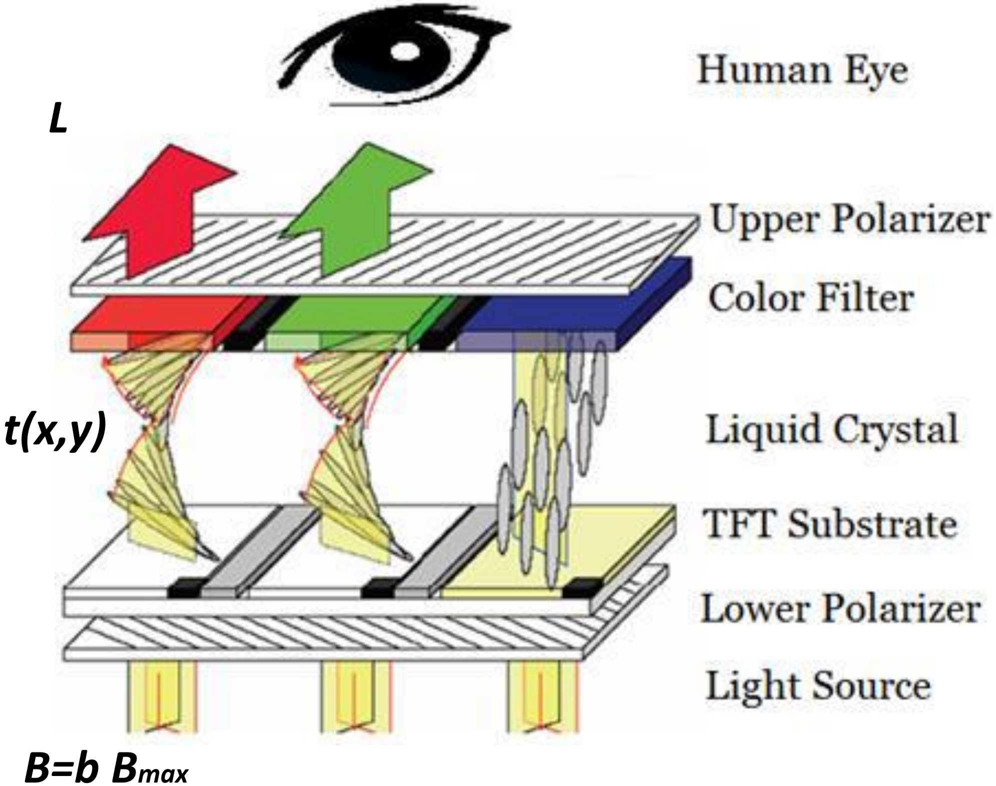


Image-Backlight Relationship

- To perceive a pixel on the display, we can model as:

$$L = b \cdot B_{MAX} \cdot [(\frac{I(x,y)}{V})^{\Gamma} + n(x,y)] + o\{I(x,y)\}$$

  - L: luminance
  - B: backlight
  - t(x,y): transmittance
  - o(x,y): luminance offset



- To perceive the same L,

$$L = 1 \cdot B_{MAX} \cdot [(\frac{I_F(x,y)}{V})^{\Gamma} + n(x,y)] + o_F(x,y)$$

$$= b \cdot B_{MAX} \cdot [(\frac{I_C(x,y)}{V})^{\Gamma} + n(x,y)] + o_C(x,y)$$

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Image-Backlight Relationship

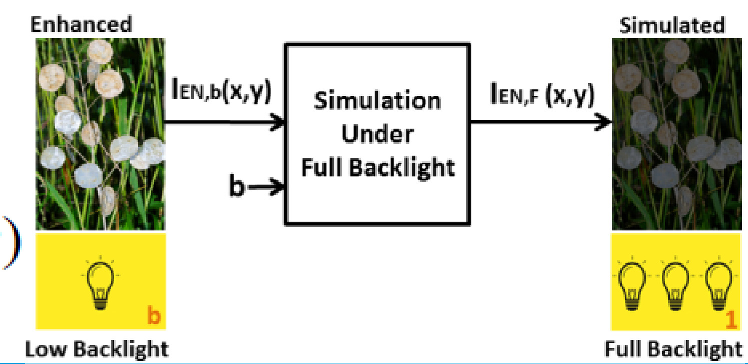
- We can simulate
  - the compensated image on low backlight
  - by scaling-down the enhanced image on full backlight

- The scale-down factor = $b^{1/\Gamma}$

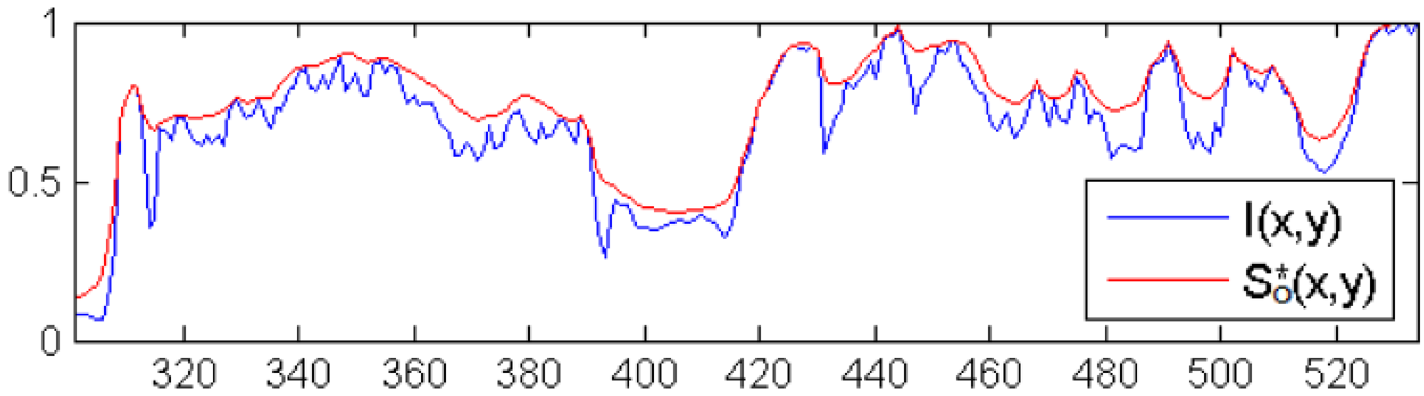
$$I_F(x,y) = V\cdot[b\cdot(\frac{I_C(x,y)}{V})^\Gamma + (b-1)\cdot n(x,y) + \frac{o_C(x,y)-o_F(x,y)}{B_{MAX}}]^{\frac{1}{\Gamma}}$$

$$L = b\cdot B_{MAX}\cdot(\frac{I_C(x,y)}{V})^\Gamma = B_{MAX}(b^{\frac{1}{\Gamma}}\cdot I_C(x,y))^\Gamma$$

$$I_F(x,y) = 1\cdot[b\cdot\left(\frac{I_C(x,y)}{1}\right)^\Gamma + 0]^{\frac{1}{\Gamma}} = b^{\frac{1}{\Gamma}}\cdot I_C(x,y)$$



Variation-Based Illumination-Reflectance Model



- To model an image: $I(x,y) = S(x,y) \cdot R(x,y)$
  - I: intensity
  - S: illumination
  - R: reflectance

$$S_{sub,-n}(x,y) = \frac{I_{sub,-n}(x,y)}{R_{sub,-n}(x,y)} \geq I_{sub,-n}(x,y)$$

$$R(x,y) = \frac{I(x,y)}{S_0^*(x,y)}$$

- Illumination Estimator:

$$F(S_{sub,-n}(x,y)) = \int_\Omega \| \nabla S_{sub,-n}(x,y) \|^2 + w_{-n}(x,y) \cdot \| S_{sub,-n}(x,y) - I_{sub,-n}(x,y) \|^2$$

$$w_{-n}(x,y) \approx D_{-n}\{\alpha \cdot [| I(x,y) \otimes H_x(x,y) | + | I(x,y) \otimes H_y(x,y) |]\}$$

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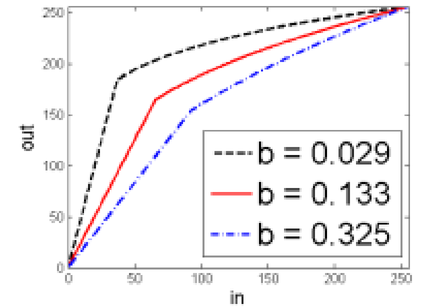
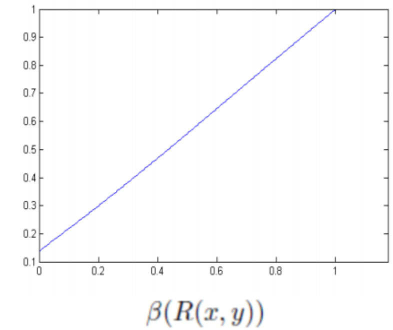
Intensity Enhancement & Saturation Boosting

- Intensity Enhancement:

$$
\begin{aligned}
& I_{EN,b}(x,y) \\
&= S_{EN,b}(x,y)\cdot R_{EN}(x,y) \\
&= V\cdot LUT_b\left(\frac{S_0^*(x,y)}{V}\right)\cdot \exp\left(g\cdot \frac{1}{1+e^{-\beta\cdot\log(R(x,y))}}-\frac{1}{2}\right)
\end{aligned}
$$



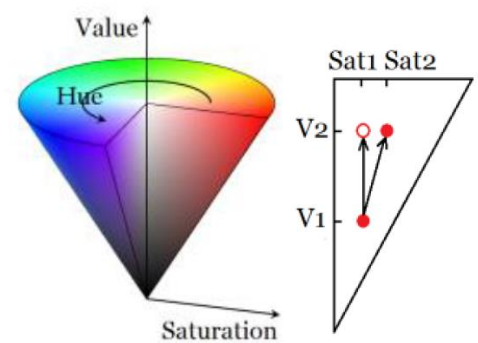
Enhancement of S



Enhancement of R

- Saturation Adjustment:

$$
Sat_{EN}(x,y) = \left(\max\left\{\frac{I_{EN,b}(x,y)}{I(x,y)},1\right\}\right)^{\gamma}\cdot Sat(x,y)
$$



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Dataset, Subjective Test, and Time

- Dataset:

Twenty images for our BRISQUE test and MOS test.

- Subjective Test:
  - BRISQUE
  - MOS (12 subjects)

Method	Huang[6]	Pei[7]	Shih[9]	Retinex	Ours
Brisque	18.80	18.60	18.00	18.89	**16.73**
MOS	2.921	2.608	3.388	1.650	**3.521**

Table. 1. Evaluations on BRISQUE test and MOS test. The lowest BRISQUE values and the highest MOS values reveal that our system outperforms than the current existing systems in both numerical and subjective examinations.

- Processing Time:
  - iter. vs BRISQUE
  - iter. vs time
  - hardware

Numbers of Iterations	50	20	10
Brisque	16.73	16.87	17.30
Intel i7-4790 using Matlab	0.287	0.150	0.101
Strong ARM using C (Est.)	0.086	0.045	0.030
Samsung S6 Edge (Est.)	0.0103	0.0041	0.0021

Table. 2. Evaluations on BRISQUE test and the processing time in seconds. The estimated processing time on Samsun S6 Edge is analyzed in the appendices.

Simulated Results

Original | Our Illumination | Huang [7] | Pei [8] | Shih [11] | Retinex [9,17] | Ours

Under 100% Backlight

Simulation for 13.3% Backlight

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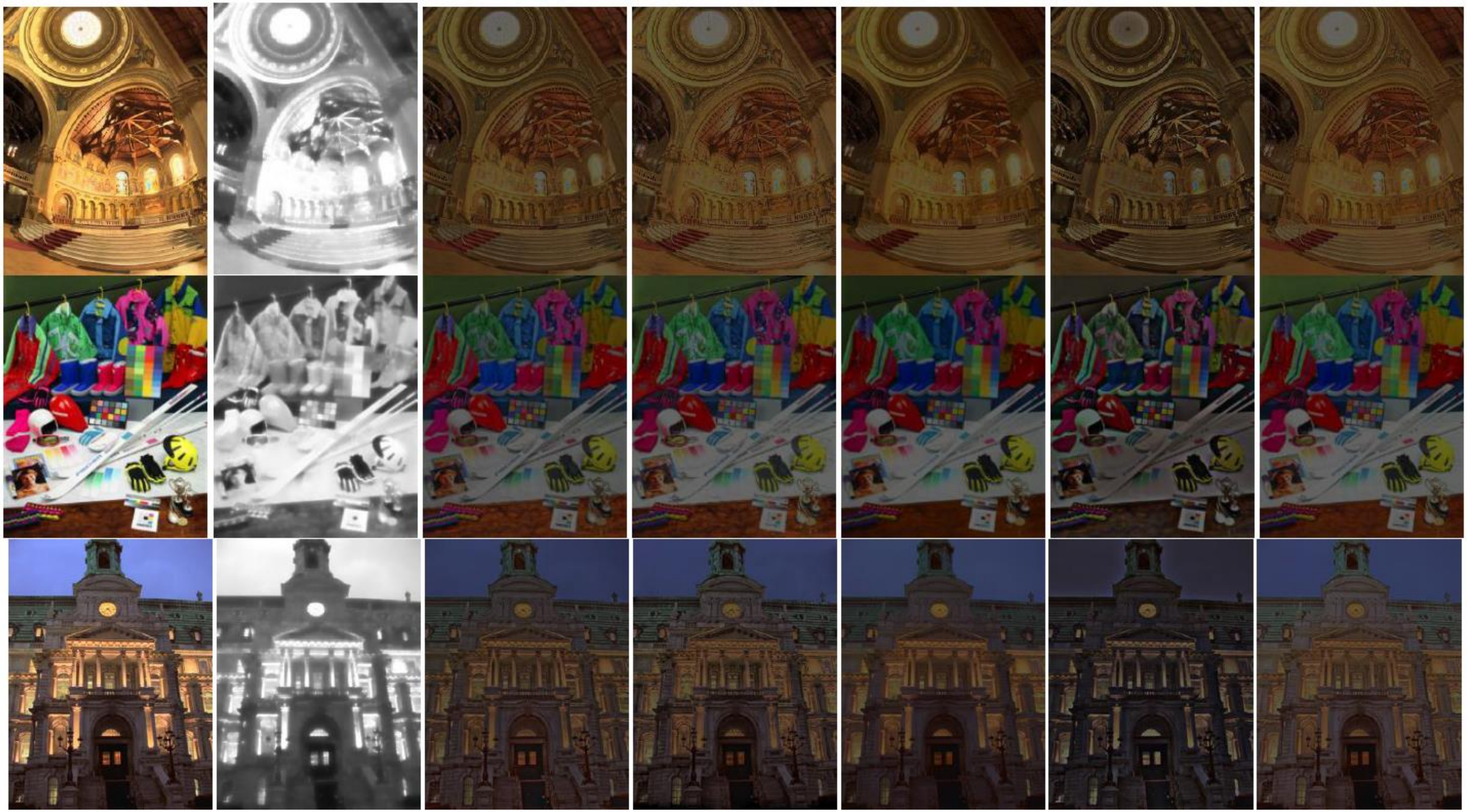
Simulated Results



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Under 100% Backlight

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