Visual Enhancement Using Sparsity-Based Image Decomposition for Low Backlight Displays

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Our proposed system:

scale down the backlight, enhance the image, save power.

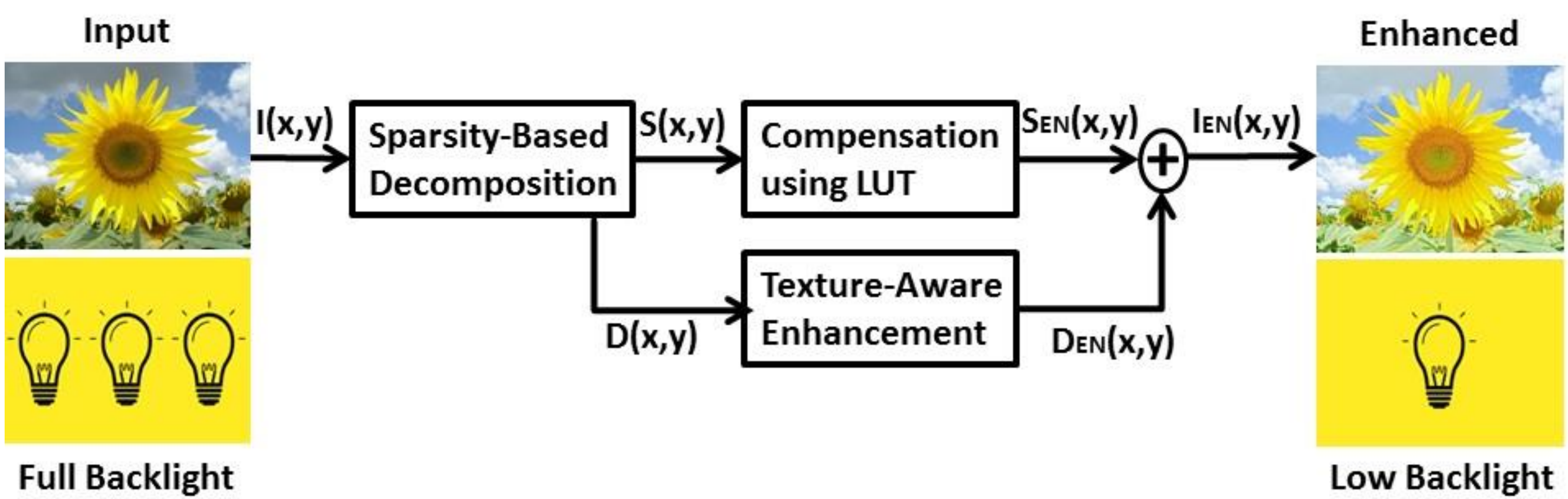


Image-Backlight Relationship

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

$$L = B \cdot t(x,y) + O(x,y) = b \cdot B_{MAX} \cdot \left(\frac{I(x,y)}{V}\right)^{\Gamma} + o\{I(x,y)\}$$

  - L: Luminance
  - B: Backlight
  - t(x,y): transmittance
  - O(x,y): Luminance offset
- To perceive the same ***L***,

$$L = 1 \cdot B_{MAX} \cdot \left(\frac{I_F(x,y)}{V}\right)^{\Gamma} + o_F(x,y)$$
$$= b \cdot B_{MAX} \cdot \left(\frac{I_C(x,y)}{V}\right)^{\Gamma} + o_C(x,y)$$

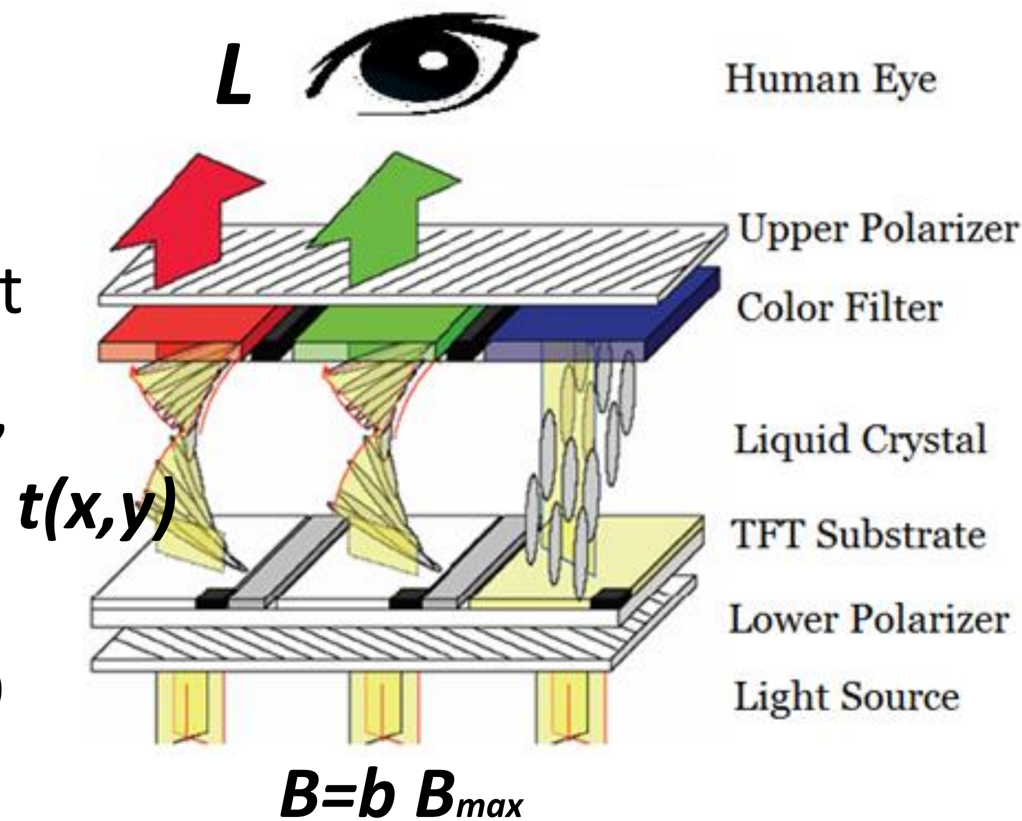


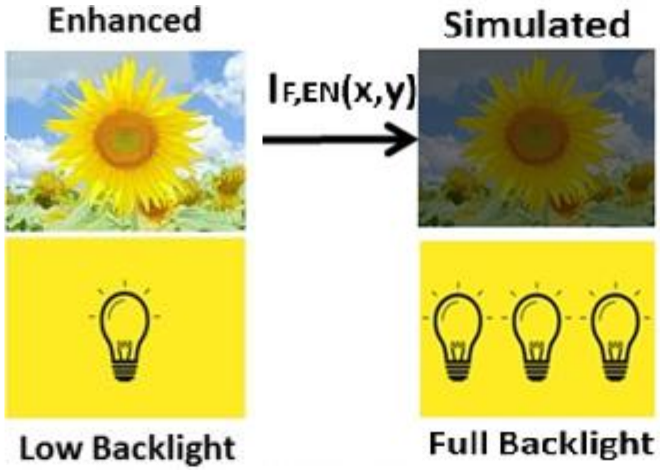
Image-Backlight Relationship

- We can simulate
  - the compensated image on low backlight
  - by scaling-down the enhanced image on full backlight
- The scale-down factor = $b^{\frac{1}{\Gamma}}$

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

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

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



Sparsity-Base Image Decomposition for Enhancement

I **=** ***S*** **+** ***D***

- To enhance an image, we can firstly decompose an image into a base layer (***S***) and a detail layer (***D***).
- We proposed a general form of sparsity-base decomposition:

$$\min_{S} \alpha \cdot \int_{\Omega} \| S - I \|^2 + (1-\alpha) \int_{\Omega} \| S - I \| + \eta \cdot \int_{\Omega} \|\| \partial S \|^2 + \lambda \cdot \int_{\Omega} \| \partial S \|_0$$

Solvers

Let's discretize it and solve *S* alternatively :

$$\min_{S,v,w} \alpha \cdot \sum_{(x,y)} \| S - I \|^2 + (1-\alpha)\cdot\gamma\cdot \sum_{(x,y)} \| S - I - v \|^2 + (1-\alpha)\cdot \sum_{(x,y)} \| v \|$$

$$+\eta \cdot \sum_{(x,y)} \| \partial S \|^2 + \beta \cdot \sum_{(x,y)} \| \partial S - w \|^2 + \lambda \cdot \sum_{(x,y)} \| w \|_0$$

To solve *S*,

$$S = F^{-1}\left\{ \frac{(\alpha+\gamma-\alpha\gamma)F(I) + (\gamma-\gamma\alpha)F(v) + \beta F^{*}(\partial)F(w)}{(\alpha+\gamma-\alpha\gamma) + (\eta+\beta)F^{*}(\partial)F(\partial)} \right\}$$

To solve *v*,

$$v = \max\{|S-I| - \frac{1}{\alpha}, 0\} \cdot \frac{S-I}{|S-I|}$$

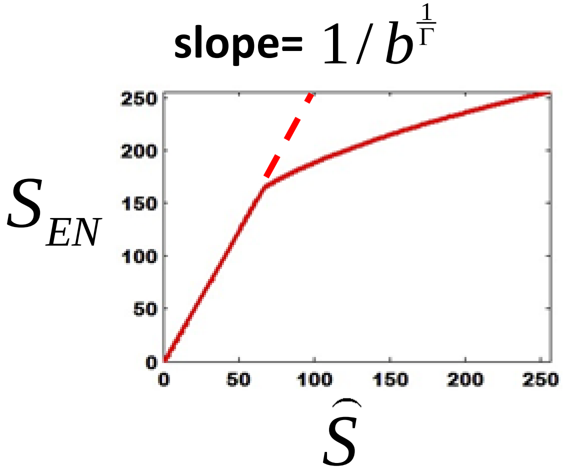
To solve *w*,

$$w = \max_{w} \sum_{(x,y)} \| \partial S - w \|^2 + \frac{\lambda}{\beta} \cdot C(x,y)$$

$$\left.\begin{aligned}
&C(x,y) = \sum_{(x,y)} |w_x(x,y)| + |w_y(x,y)| \\
&\text{where } |w_x(x,y)| + |w_y(x,y)| = 1 \\
&\text{if } \; M(x,y)\cdot(|\partial_x S(x,y)|^2 + |\partial_y S(x,y)|^2) \le \xi
\end{aligned}\right\} \text{L}_0 \text{ Norm of Gradient}$$

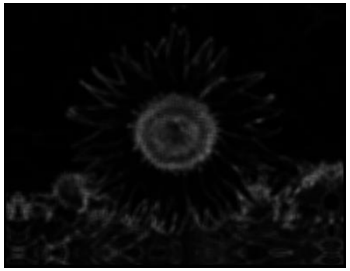
Base Compensation & Detail Enhancement

- We compensate the base layer:
  - Using a look-up table $S_{EN} = V \cdot LUT(\frac{\widehat{S}}{V})$
  - L2-distance between
    - the line with the slope $1/b^{\frac{1}{\Gamma}}$
    - gamma correction



- We can enhance the detail layer.
  - Detail: $\widehat{D} = I - \widehat{S}$
  - Enhance: $D_{EN} = g \cdot \hat{D} \cdot (\frac{V + JND(V)}{V})^{\tau}$

$$\tau = \frac{T - T_{\min}}{T_{\max} - T_{\min}} + 1$$



$$T = \frac{WTV_x^2}{WIV_x^2 + \varepsilon} + \frac{WTV_y^2}{WIV_y^2 + \varepsilon}$$

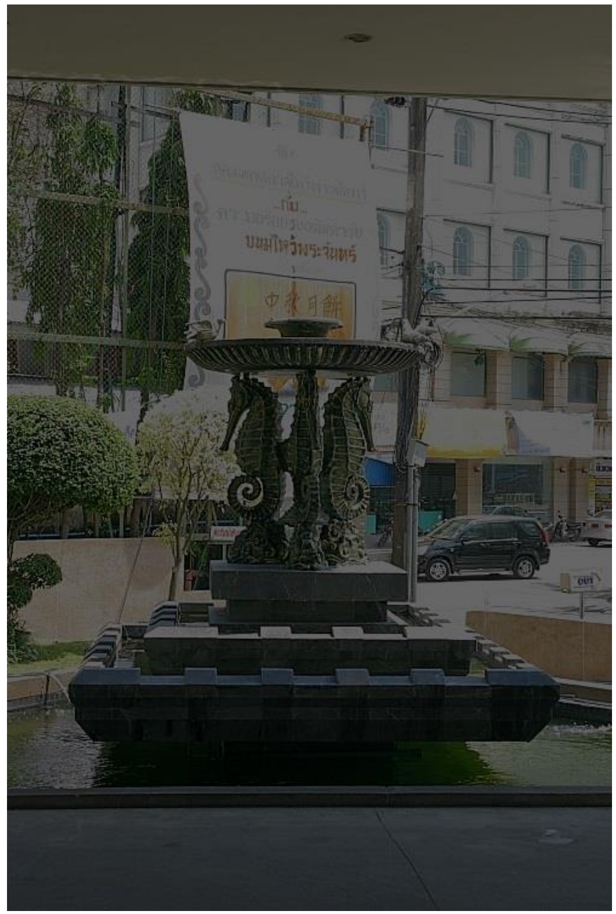
$$WTV_i = \sum_{(x,y)\in W} |\partial_i \hat{D}|$$

$$WIV_i = \left|\sum_{(x,y)\in W} \partial_i \hat{D}\right|$$

- Final Intensity: $I_{EN} = S_{EN} + D_{EN}$

Simulated Results

Original
simulation for 100% Backlight



Tsai et al.
simulation for 13.3% Backlight

Ours
simulation for 13.3% Backlight

Original
simulation for 100% Backlight

Tsai et al.
simulation for 13.3% Backlight

Ours
simulation for 13.3% Backlight