SINGLE IMAGE BRIGHTENING VIA EXPOSURE FUSION

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Challenges:

In low lighting condition,

- capturing an image via a *long exposure time* and a *small ISO value* ⟹ *clean but blurred*.
- capturing an image via *a short exposure time* and *a large ISO value* ⟹ *sharp but noisy*.

Solution:

Capturing an image via a *small exposure time* and *a small ISO value* ⟹ *clean, sharp but dark*

Applying a brightening algorithm to increase the brightness ⟹ ***clean, sharp and bright***

Single Image Brightening

- Step 1: Three ***virtual differently exposed images*** are generated from an image which is captured via a small exposure time and a small ISO value.
- Step 2: A simple algorithm is designed to fuse the three virtual differently exposed images in a new color space to produce the ***brightened image***.

Generation of Virtual Differently Exposed Images

Given an input image Z. The first virtual image $\hat{Z}_1$ is generated by using a non-decreasing function to brighten the under-exposed regions of the image Z as well as a global factor to increase the brightness of the whole image with negligible increment on the brightness of the brightest areas. The image $\hat{Z}_1$ is produced as

$$\hat{Z}_{1,c}(p) = Y(p)(1+\exp^{-14Y^{1.6}(p)})Z_c(p)$$

- c: the color channel
- $Y(p)$: the luminance component of the pixel $Z(p)$

The second and the third images are generated follows:

$$\hat{Z}_{2,c}(p) = \frac{5(256-\bar{y})}{32}\hat{Z}_{1,c}(p)$$

$$\hat{Z}_{3,c}(p) = \frac{256-\bar{y}}{4}\hat{Z}_{1,c}(p)$$

- $\bar{y}$: the average value of the luminance components of all under-exposed and well-exposed pixels

Fusion of Differently Exposed Images in a New Color Space

A simplified CIELAB color space is introduced as follows:

$$\begin{cases} \tilde{Z}_{i,1}(p) = \Psi(\check{Z}_{i,2}(p)) - 32 \\ \tilde{Z}_{i,2}(p) = 2(\Psi(\check{Z}_{i,1}(p)) - \Psi(\check{Z}_{i,2}(p))) \\ \tilde{Z}_{i,3}(p) = \Psi(\check{Z}_{i,2}(p)) - \Psi(\check{Z}_{i,3}(p)) \end{cases}$$

- $\check{Z}_{i,2}(p)$, $\check{Z}_{i,1}(p)$ and $\check{Z}_{i,3}(p)$: $\begin{cases} \check{Z}_{i,1}(p) = \frac{126\hat{Z}_{i,1}(p)+79\hat{Z}_{i,2}(p)+51\hat{Z}_{i,3}(p)}{256} \\ \check{Z}_{i,2}(p) = \frac{45\hat{Z}_{i,1}(p)+208\hat{Z}_{i,2}(p)+3\hat{Z}_{i,3}(p)}{256} \\ \check{Z}_{i,3}(p) = \frac{3\hat{Z}_{i,2}(p)+253\hat{Z}_{i,3}(p)}{256} \end{cases}$

- $\Psi(z)$: $\Psi(z) = \begin{cases} 16z^{0.5}; & \text{if } z \geq 64 \\ z+64; & \text{otherwise} \end{cases}$

One color component $\tilde{Z}_{i,1}(p)$ is fused via the multi-scale algorithm:

$$L\{\tilde{Z}_1^{(f)}(p)\}^l = \sum_{i=1}^{3}[L\{\tilde{Z}_{i,1}(p)\}^l G\{W_i(p))\}^l]$$

- $L\{\tilde{Z}_{i,1}(p)\}^l$: Laplacian pyramid of image $\tilde{Z}_{i,1}$
- $G\{W_i(p))\}^l$: Gaussian pyramid of weight map $W_i(p)$

Two color components are fused together via a single-scale method as follows:

$$\tilde{Z}_c^{(f)}(p) = \frac{\sum_{i=1}^{3} W_i(p)\tilde{Z}_{i,c}(p)}{\sum_{i=1}^{3} W_i(p)} \; ; \; c = 2,3$$

The final image is computed as:

$$\begin{cases} Z_1^{(f)}(p) = \frac{601\Psi^{-1}(\hat{Z}_1^{(f)}(p))-227\Psi^{-1}(\hat{Z}_2^{(f)}(p))-118\Psi^{-1}(\hat{Z}_3^{(f)}(p))}{256} \\ Z_2^{(f)}(p) = \frac{-130\Psi^{-1}(\hat{Z}_1^{(f)}(p))+364\Psi^{-1}(\hat{Z}_2^{(f)}(p))+22\Psi^{-1}(\hat{Z}_3^{(f)}(p))}{256} \\ Z_3^{(f)}(p) = \frac{2\Psi^{-1}(\hat{Z}_1^{(f)}(p))-4\Psi^{-1}(\hat{Z}_2^{(f)}(p))+259\Psi^{-1}(\hat{Z}_3^{(f)}(p))}{256} \end{cases}$$

(a) (b) (c) (d)

Fig 1. An image captured at day time but with dark human subjects (Fig.1(a)) and its three virtual differently exposed images.

The details in the under-exposed regions of Fig. 1(a) are more visible in Fig. 1(d). With the three virtual differently exposed images, the brightest areas are well-exposed in the image Fig. 1(b) , the darkest regions are well-exposed in Fig. 1(d), and other parts are well-exposed in Fig. 1(c). After three virtual differently exposed images are generated, they will be fused together to produce the final image.

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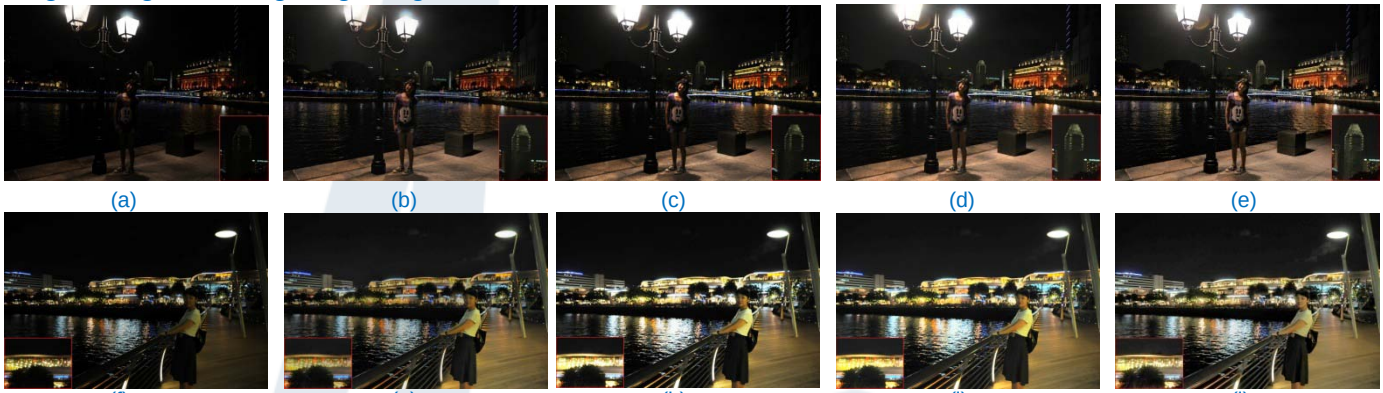
Brightening of Low-lighting Images

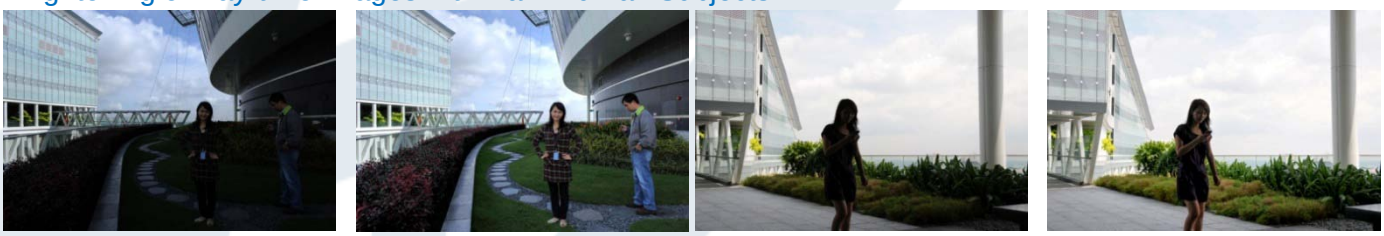


(a) (b) (c) (d) (e)

(f) (g) (h) (i) (j)

Fig. 2. Comparison of different image enhancement algorithms. (a, f) low-lighting images; (b, g) brightened images by the brightening algorithm [12]; (c, h) brightened images by the Photoshop CS5; (d, i) brightened images by the algorithm in [10]; (e, j) brightened images by the proposed algorithm.

Brightening of Day-time Images with Dark Human Subjects



(a) (b) (c) (d)

Fig. 3. Images with dark objects and the enhanced images. (a, c) images with dark objects; (b, d) brightened images by the proposed algorithm.

Capturing of Images for HDR Scenes

(a) (b) (c)

(d) (e) (f)

Fig. 4. Comparison of different HDR imaging methods. (a, b, c) three differently exposed images; (d) an image by the algorithm in [13]; (e) an image by the algorithm in [14]; (f) an image by the proposed brightening algorithm with the input image as in Fig.4(b).