Retinex-Based Perceptual Contrast Enhancement in Images Using Luminance Adaptation

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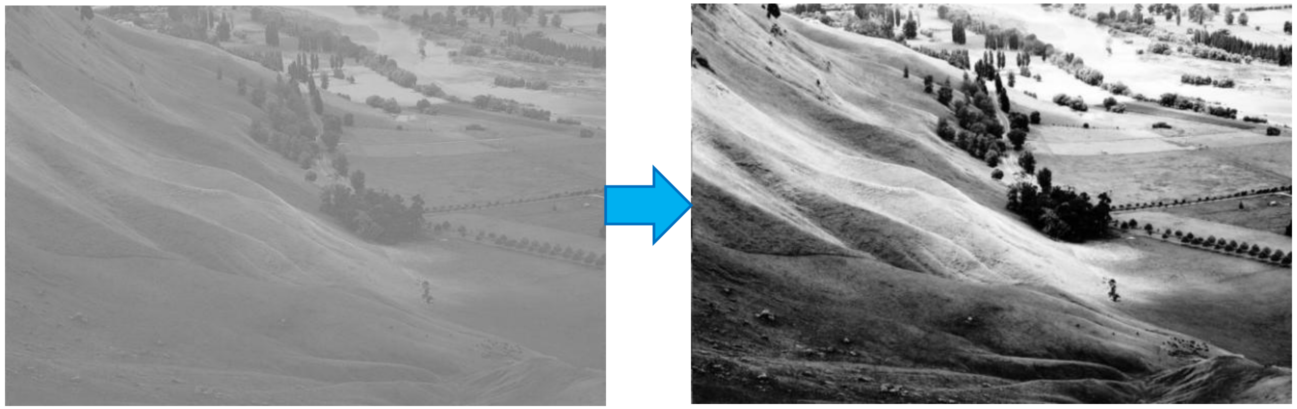
Image Contrast Enhancement

- Bring out obscured **details** or enhance **contrast** of an image with a low dynamic range to achieve visually-pleasing and informative results;
- Applications: Medical image analysis, remote sensing, display enhancement;



Contrast Enhancement

Applications

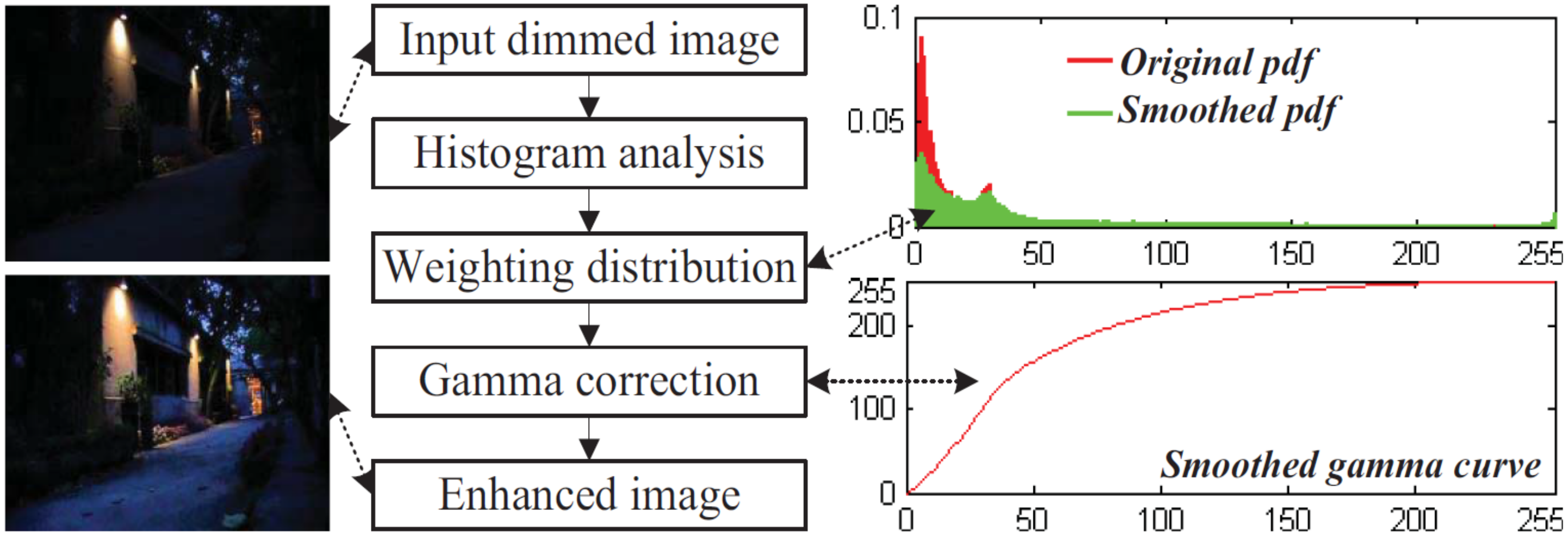
AGCWD (TIP 2013)

- Adaptive gamma correction after weighting distribution (**AGCWD**)
  - **Weighting distribution** of the histogram:

$$pdf_w(l) = pdf_{max}\left(\frac{pdf(l) - pdf_{min}}{pdf_{max} - pdf_{min}}\right)^{\alpha}$$

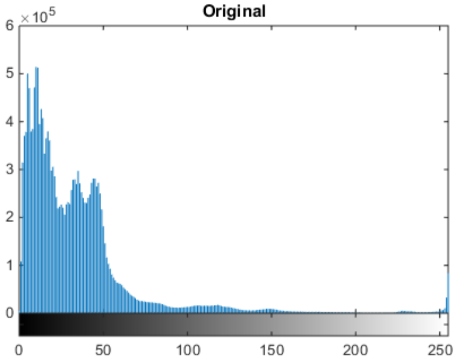
  - **Adaptive gamma correction**:

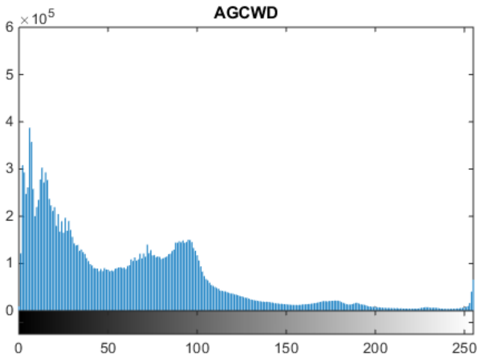
$$T(l) = l_{max}(l/l_{max})^{\gamma} = l_{max}(l/l_{max})^{1-cdf_w(l)}$$



AGCWD (TIP 2013)

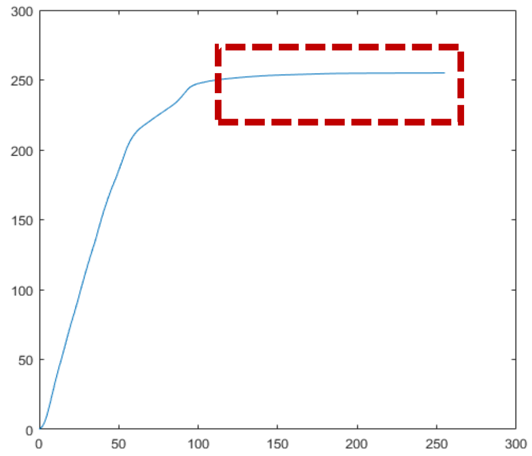
- Low light image enhancement by AGCWD
  - Low light images: Low dynamic range (dark tone), weak color;
    - Low light image enhancement often causes **over-enhancement**;
  - AGCWD
    - **Enhance contrast while preserving its natural tone**;





AGCWD (TIP 2013)

- Problems in AGCWD
  - Details are lost in very bright regions from **strong illumination**;
  - Reason: **Excessive compression,** i.e. **a very narrow dynamic range is allocated to highlight regions;**

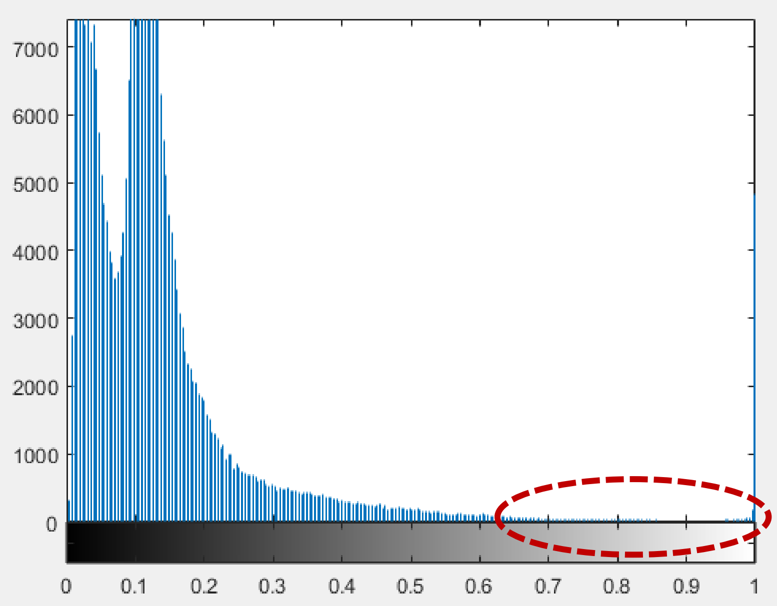


AGCWD (TIP 2013)

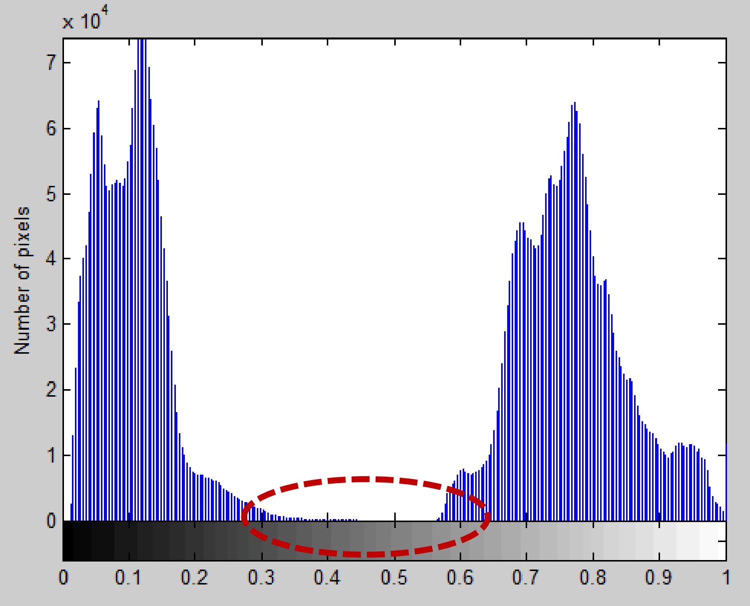
- Problems in AGCWD
  - Also, detail loss appears in **daylight images with strong dark shadows**;
  - **Mid-level intensities** have very small probability;

AGCWD (TIP 2013)

- Analysis:
  - Highlight regions are much smaller than dark regions in **low light images**;
  - Mid-level intensity regions in **shadow images** are the same ;
  - **Imbalance of the dynamic range allocation** causes **detail loss** after contrast enhancement by AGCWD;



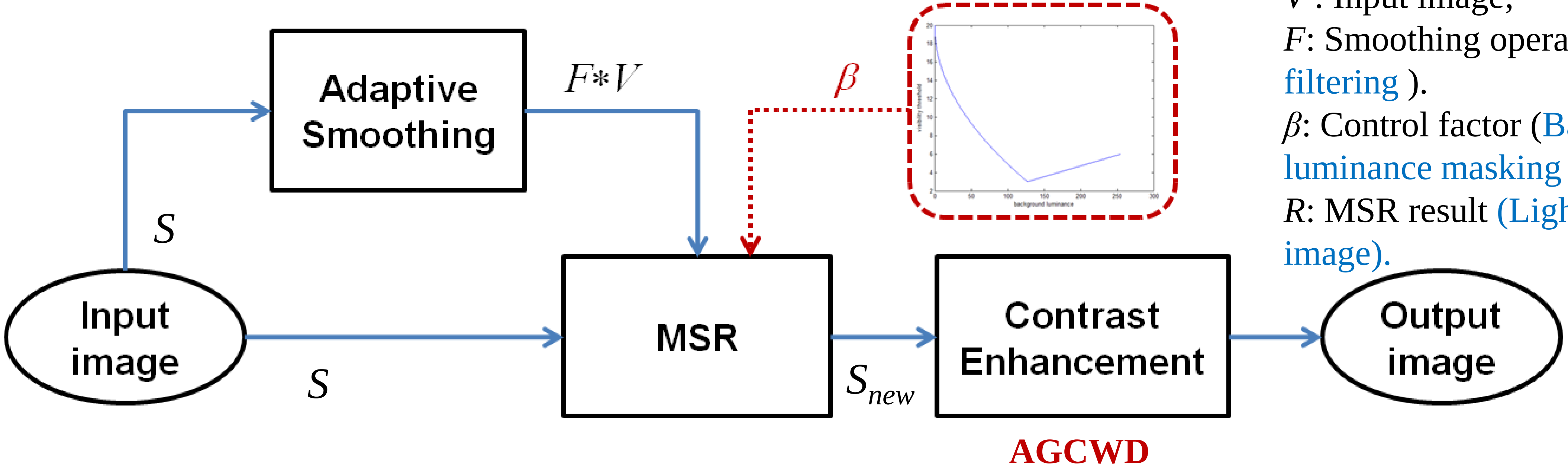
Low light images



Daylight images with strong shadows

Proposed Approach

- Retinex-based contrast enhancement using luminance adaptation
  - **Histogram adjustment** for dynamic range allocation and detail preservation based on Retinex theory;
  - **Perceptual contrast enhancement** using luminance adaptation;



MSR: Multi-scale retinex;
V : Input image;
F: Smoothing operator (Adaptive filtering).
β: Control factor (Background luminance masking).
R: MSR result (Light-weakened image).

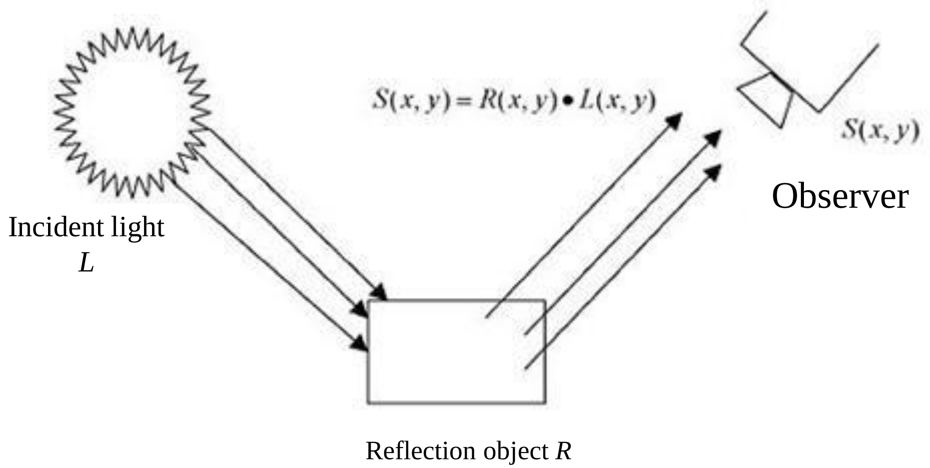
Retinex Theory

- Based on physical imaging model:

$$S(x,y) = R(x,y) \cdot L(x,y)$$

$R(x,y)$ ***Reflectance***
$L(x,y)$ ***illumination***

- Basic assumption:
  - Original image *S* is the product of *R* and *L* (***R*: invariant**);
  - Single scale retinex (SSR), **multi-scale retinex (MSR)**;



Retinex-Based Histogram Adjustment

$$S(x,y) = R(x,y) \cdot L(x,y)$$

$$S_{new}(x,y) = R(x,y) \cdot L(x,y)^{\gamma}$$

By adjusting *L*

$$\log S_{new}(x,y) = \log R(x,y) + \gamma \cdot \log L(x,y)$$

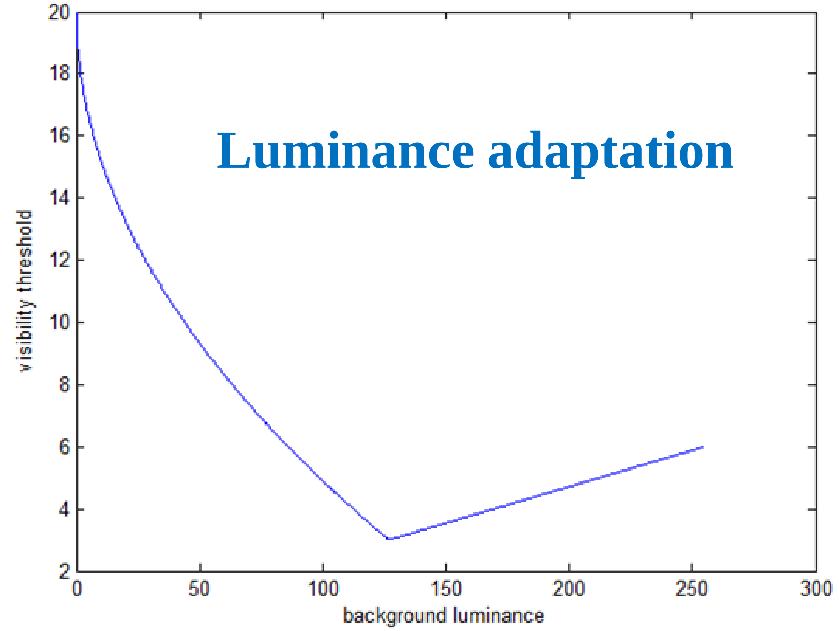
$$\log S_{new}(x,y) = [\log S(x,y) - \log L(x,y)] + \gamma \cdot \log L(x,y)$$

$$\log S_{new}(x,y) = \log S(x,y) - (1-\gamma) \cdot \log L(x,y)$$

$$\log S_{new}(x,y) = \log S(x,y) - \beta \cdot \log L(x,y)$$

$$= \sum_{n=1}^{N} w_n \cdot \{\log S(x,y) - \beta \cdot \log[F_n(x,y) * S(x,y)]\}$$

By using MSR



$$\Rightarrow \quad \beta = 1 - \gamma$$

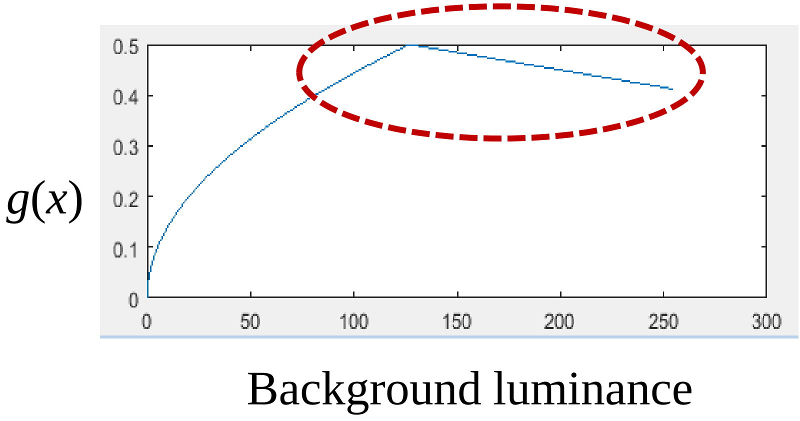
How to assign β?

Retinex-Based Histogram Adjustment

Original image

β = 0.8

β = 0.4



$$\beta = g\left(JND(F_n(x,y) * S(x,y))\right)$$

JND ----- **Background luminance masking**

$$g(x) = k\left(-\frac{1}{17}x + \frac{20}{17}\right)$$

Linear equation by maximum and minimum JND values

β is adaptive to the local content (background luminance**) in an image:**

In dark regions, β is smaller, thus making the MSR result similar to the original image;

In bright regions, β is bigger, and thus the illumination is weakened;

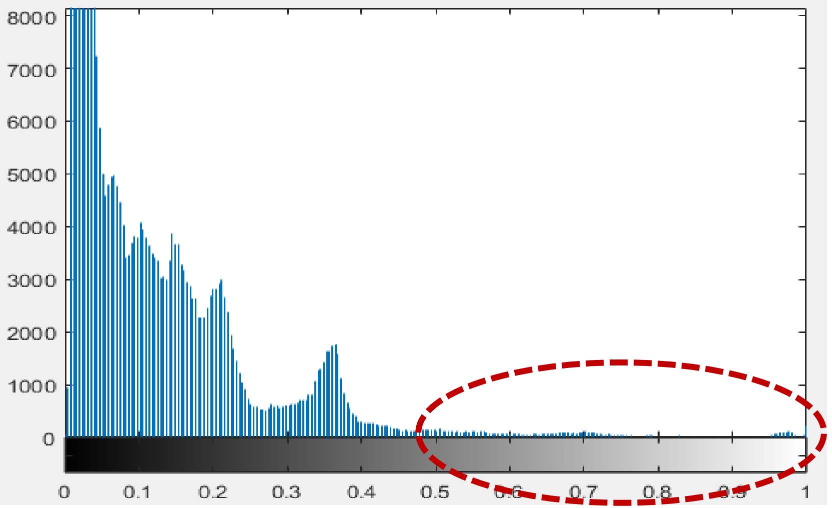
The smaller β, the more similar result to the original image;

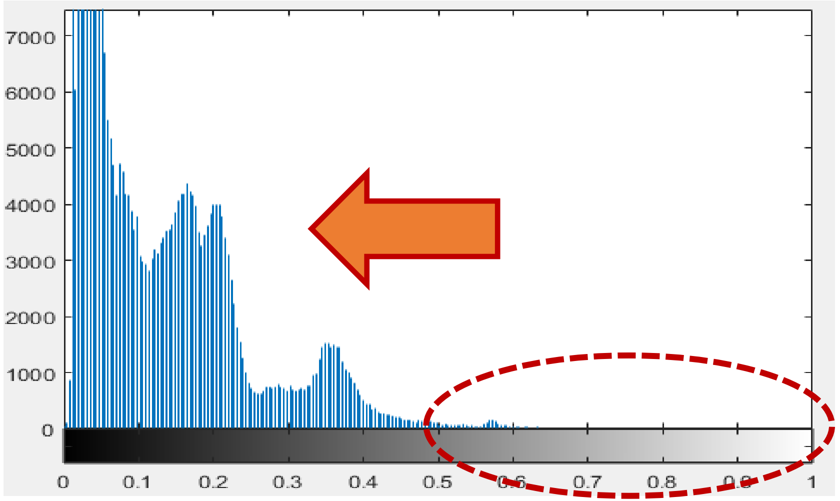
The bigger β, the more obvious details;

Retinex-Based Histogram Adjustment

S

S_{new}





Algorithm

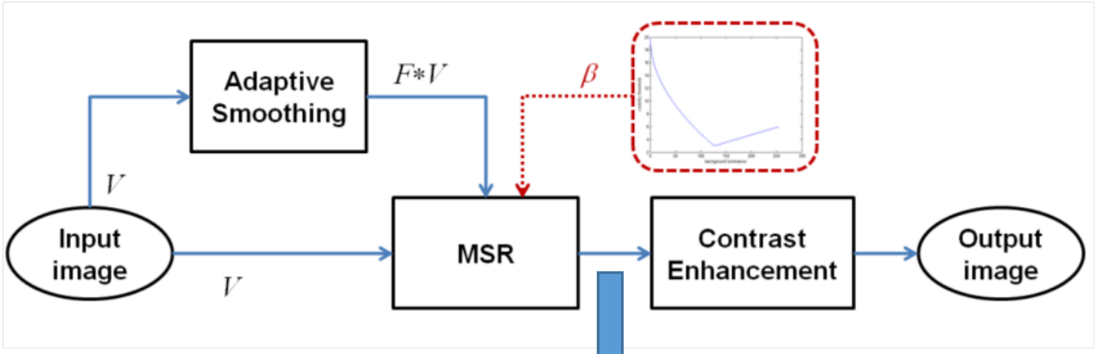
Algorithm 1 Retinex-based perceptual contrast enhancement

Input: Input image S, scale σ_n.

- $V \leftarrow RGBtoHSV(S)$.
- Illumination layer $L \leftarrow$ adaptive Gaussian filtering with σ_n on V.
- **for** each pixel **do**
  - Visibility threshold $T_l \leftarrow L$ by (8).
  - Weakening factor $\beta \leftarrow T_l$ by (9).
- **end for**
- **for** each pixel p **do**
  - Calculate R for all pixels $\leftarrow \beta$ of target pixel by (7).
  - R_{max} and $R_{min} \leftarrow \exp(R)$.
  - $I_{wea} = \frac{R_p - R_{min}}{R_{max} - R_{min}} + R_{min}$ of p.
- **end for**
- $I_{out} \leftarrow AGCWD(I_{wea})$.

Output: Enhanced image I_{out}.

MSR



$I_{wea} = S_{new}$

Experimental Results

- Hardware: a PC with Intel Core Duo 2.33GHz CPU and 4.00GB RAM;
- Software: Windows 7 and MATLAB R2015b;

- Testing dataset:
  - *Car, Campus, Carnival, and Seaside* (**Low light images**);
  - *Church, DSCN, Alley, City, and Villa* (**Shadow images**) ;
  - Size: 720x480~2048x1366;

- Evaluation metrics:

  (1) Discrete entropy (DE): Amount of **detail information** in an image;

  (2) Feature similarity (FSIM): **Feature similarity** between the enhanced and original images;

  (3) Local-tuned-global (LTG): **Perceptual quality assessment** by measuring visual saliency from local distortions and global quality degradation;

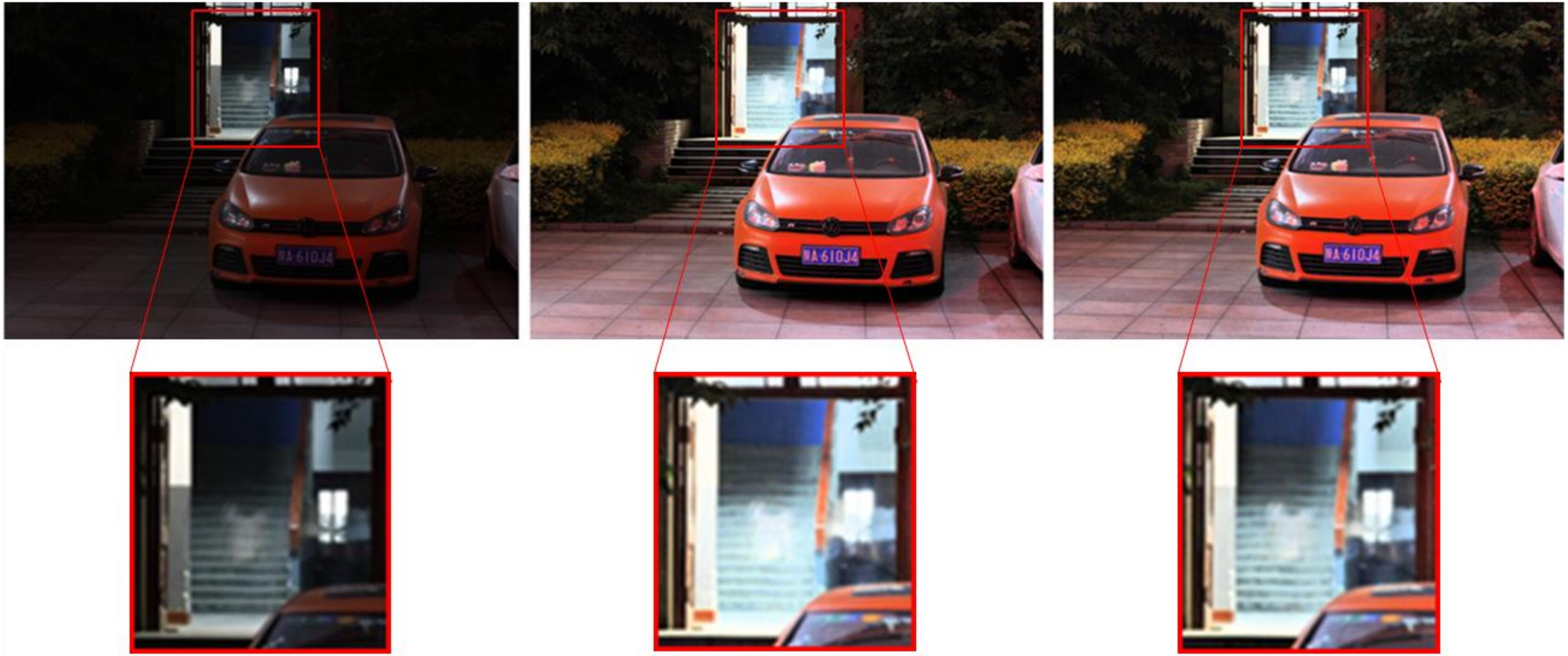
Experimental Results

[7]: AGCWD

Metric	DE		FSIM		LTG	
Image	[7]	PRO	[7]	PRO	[7]	PRO
Church	7.3411	7.7241	0.8793	0.8983	0.9915	0.9918
Car	7.3596	7.4799	0.7609	0.7568	0.9811	0.9776
City	7.3328	7.7161	0.9780	0.9800	0.9986	0.9970
Campus	7.3596	7.3900	0.7256	0.7219	0.9734	0.9699
DSCN	7.2818	7.6306	0.8998	0.8927	0.9916	0.9900
Seaside	7.2770	7.3404	0.8866	0.8825	0.9908	0.9905
Alley	7.5380	7.6272	0.8694	0.8563	0.9897	0.9882
Carnival	6.8583	7.0313	0.8212	0.8165	0.9833	0.9824
Villa	7.2983	7.4992	0.7934	0.8420	0.9847	0.9862
Average	7.2940	7.4932	0.8460	0.8496	0.9886	0.9857

Low Light Images

Low Light Images



Original image AGCWD Proposed method

Shadow Images

Original image AGCWD Proposed method

Shadow Images

Original image

AGCWD

Proposed method

Conclusions

- We have proposed **retinex-based perceptual contrast enhancement** based on luminance adaptation.

- We have solved the **dynamic range allocation problem** which causes detail loss in an image;
- **Histogram adjustment** using a retinex-based framework by minimizing the illumination effect;
- **Perceptual enhancement** using luminance adaptation;

- Experimental results demonstrate that the proposed method **successfully enhances contrast in images while keeping details** in highlight regions.

THANK YOU!