Image Enhancement

Contrast Enhancement

High Pass Filter

Unsharp Mask

Fog (Haze) Removal

Lecturer: Sang Hwa Lee

Image Enhancement

- Processing to improve contrast and visual quality
  - Changing the original image for subjective quality
- Main topics
  - Contrast enhancement
  - Noise reduction
  - Sharpening
  - Colorization
- Applications
  - Image quality improvement
  - Feature detection and recognition

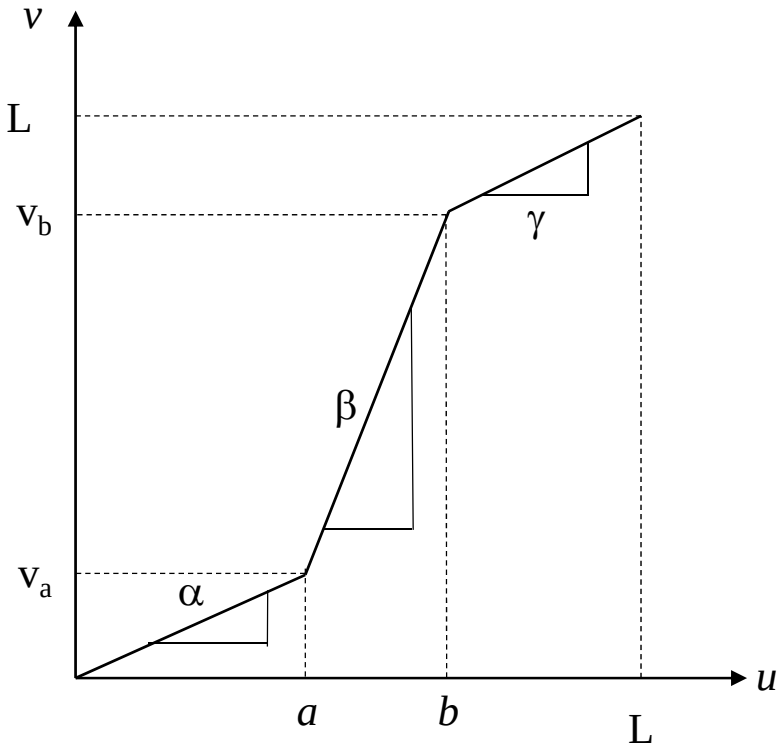
Linear Contrast Stretching (1)

- Parametric stretching

$$v = f(u) \quad u \in [0, L], v \in [0, L]$$

$$v = \begin{cases} \alpha u, & 0 \le u < a \\ \beta(u-a) + v_a, & a \le u < b \\ \gamma(u-b) + v_b, & b \le u < L \end{cases}$$

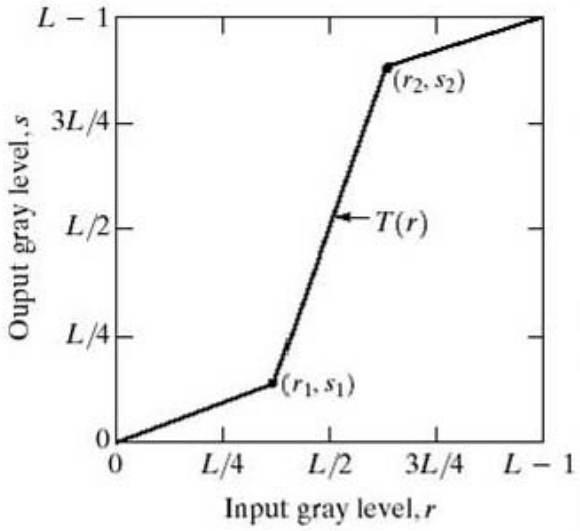
$$\alpha = \gamma = 0$$

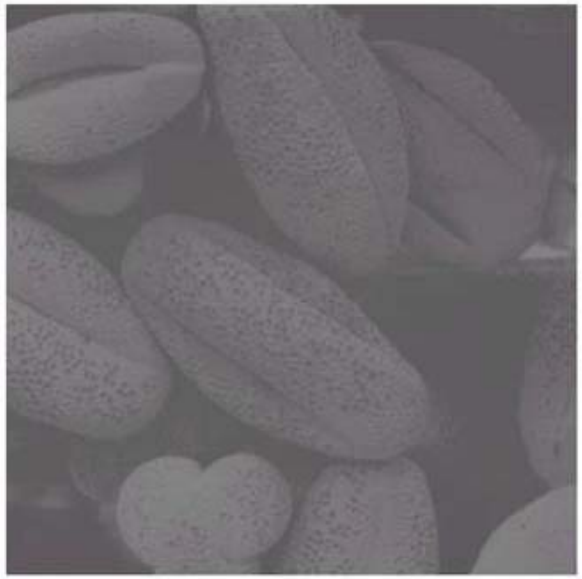


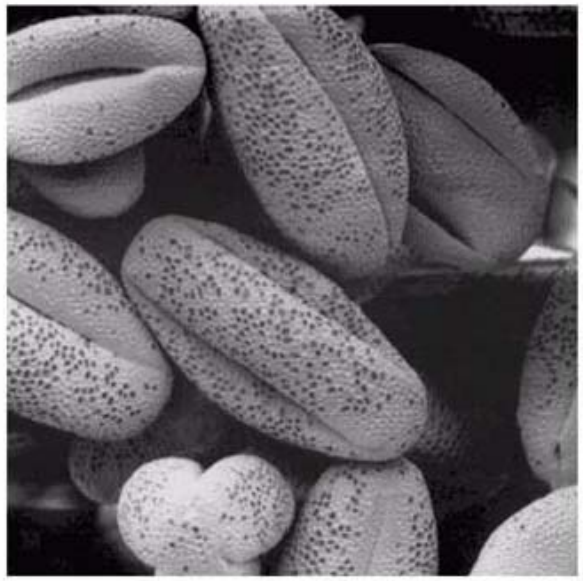
  - Clipping: $a=b\equiv t \quad u\in[a,b]$
  - Thresholding:
    - Output : Binary image

Linear Contrast Stretching (2)

Required to control
The parameters







Linear Contrast Stretching (3)

$\alpha = 0.5$
$\beta = 0.5$
$\gamma = 1.5$

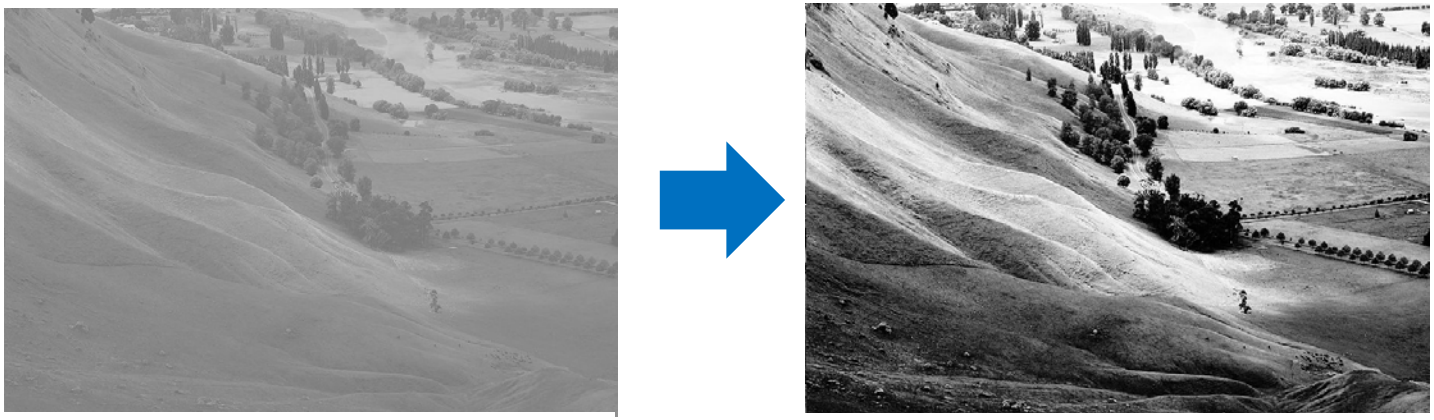
$\alpha = 1.5$
$\beta = 0.5$
$\gamma = 0.5$

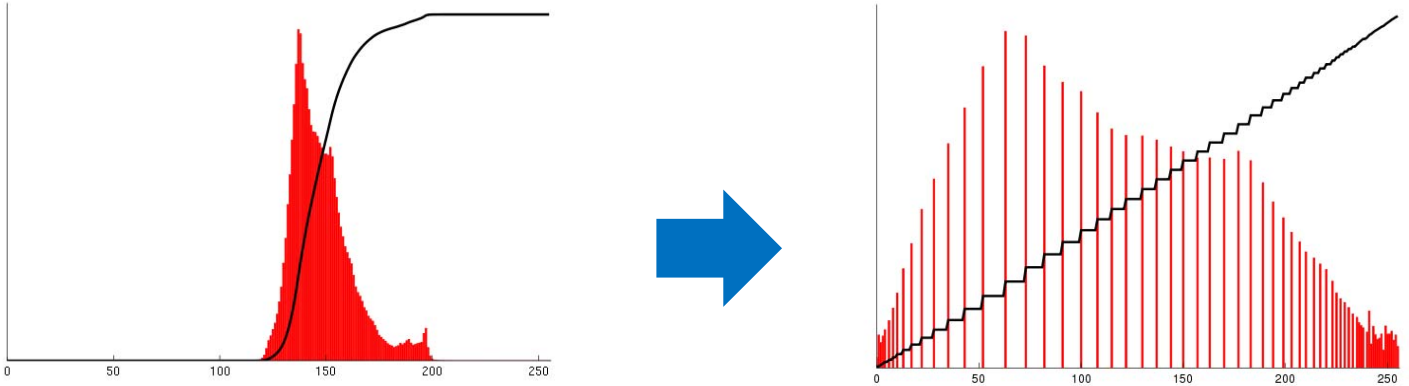
$\alpha = 0.5$
$\beta = 1.5$
$\gamma = 0.5$

Contrast Stretching, a = 80, b= 160

Histogram Equalization

- Automatic statistical and non-linear modification of intensity distribution





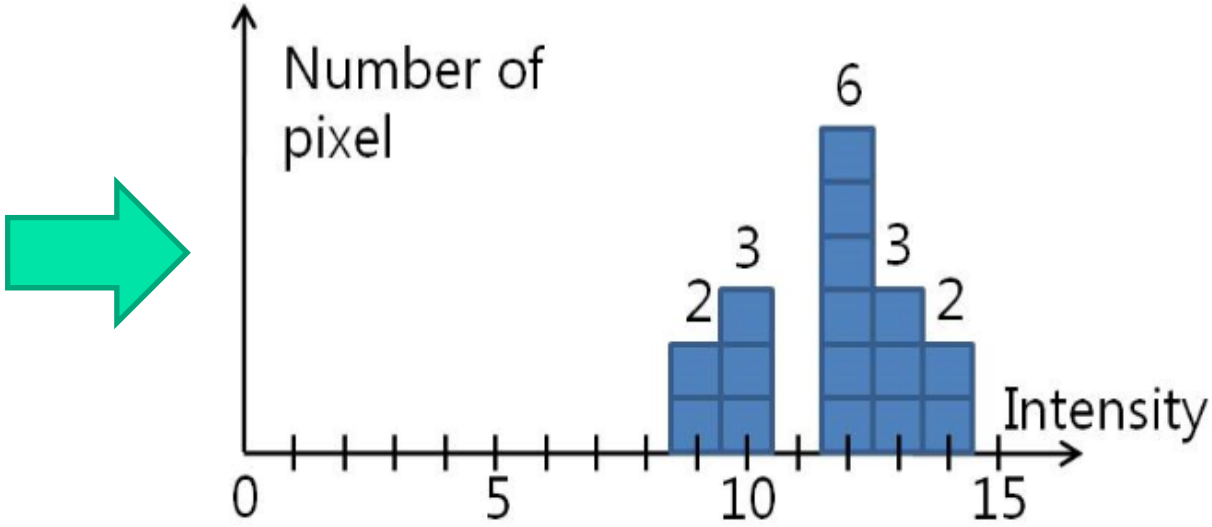
Intensity histogram (red) and cumulative histogram(black curve)

Equalized intensity histogram (red) and uniform cumulative histogram(black curve)

Histogram ?

- Histogram: Number of pixels to have an intensity
  - Statistical information
  - Histogram bin: width of intensities to count the frequency

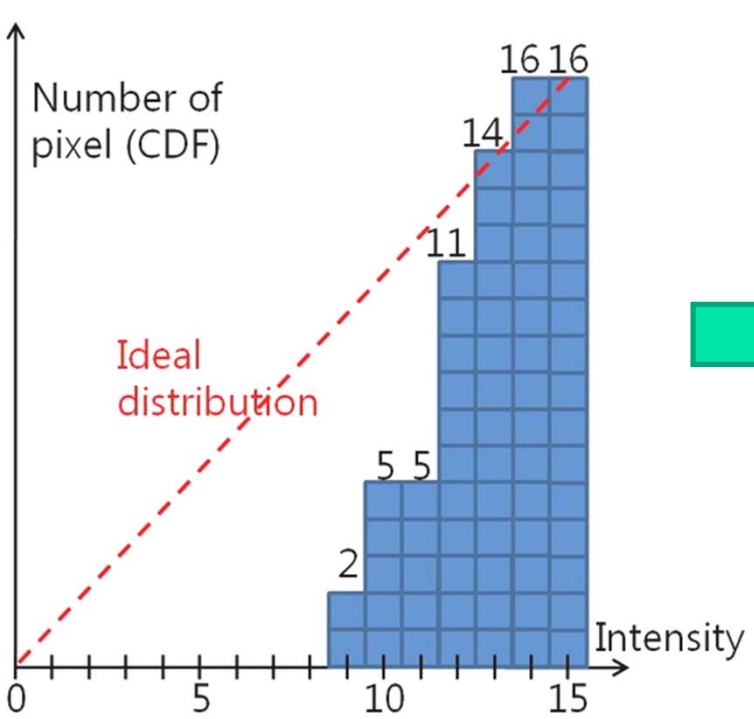
9	13	12	10
12	10	13	12
14	12	12	9
10	13	14	12



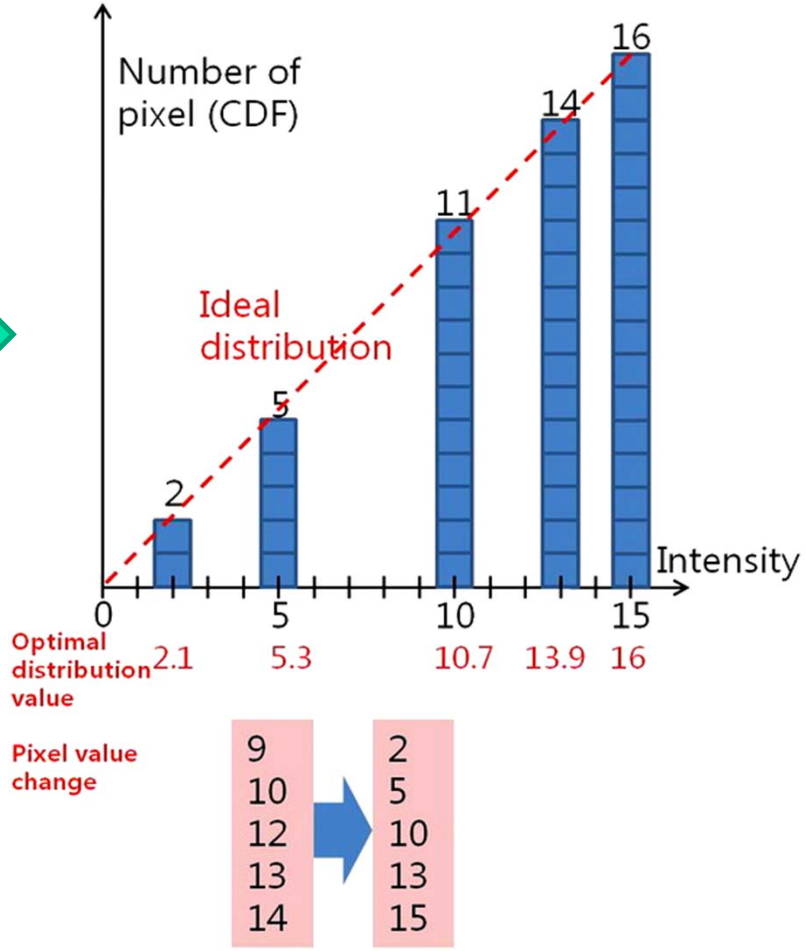
Histogram Equalization (1)

- Transform the cumulative distribution of original intensity image to be uniform
  - Linear function of CDF(cumulative distribution function)
  - Global contrast stretching
- Basic procedure
  - 1. Find the accumulated histogram of image intensity
  - 2. Normalize the accumulated histogram to be probability function
  - 3. Scale the probability 0~255 usually
  - 4. Map the intensity into the scaled value in step 4.

Histogram Equalization (2)



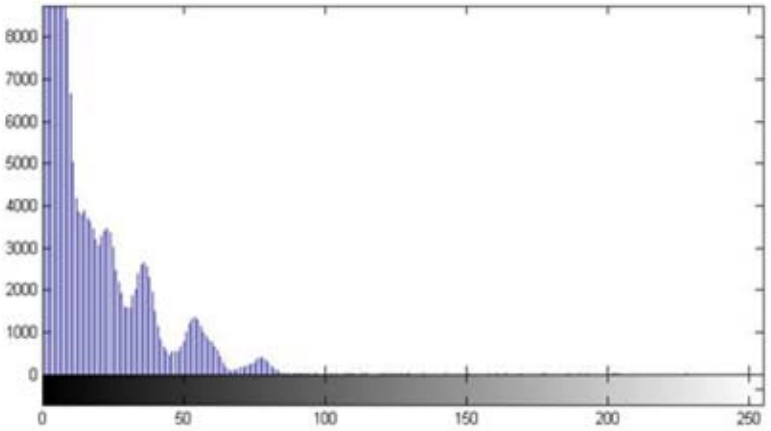
CDF (accumulative histogram)



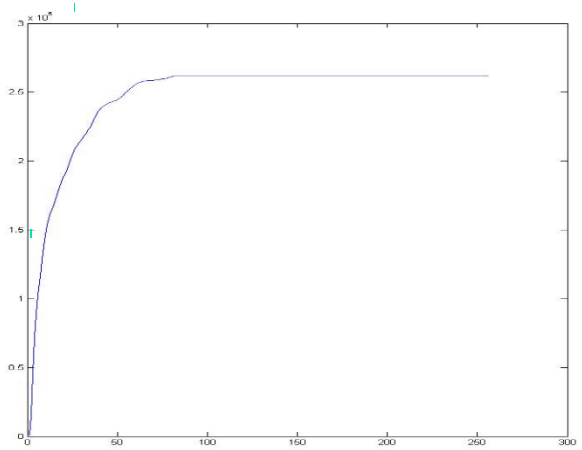
0-16 equalized histogram)

Histogram Equalization Results (1)

Original image

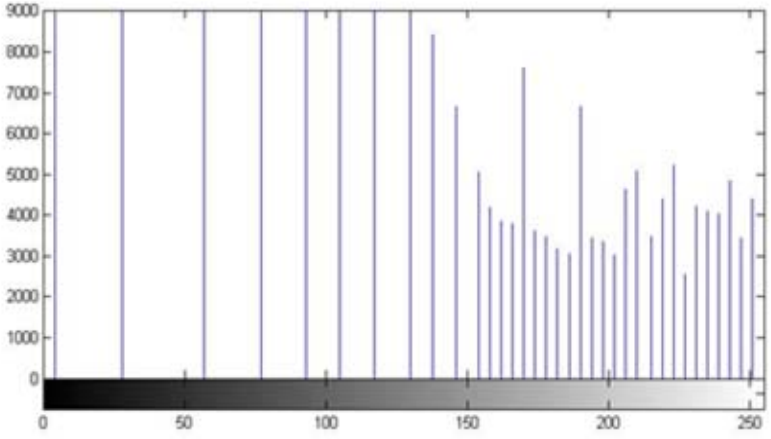


Histogram of original image

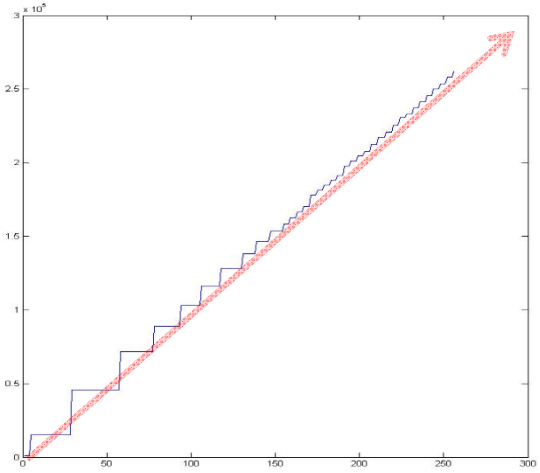


CDF of original image

HE result



Histogram of HE result



CDF of HE result

Histogram Equalization Results (2)

- Noise amplification

Original image

Histogram equalized image

Histogram Equalization Results (3)

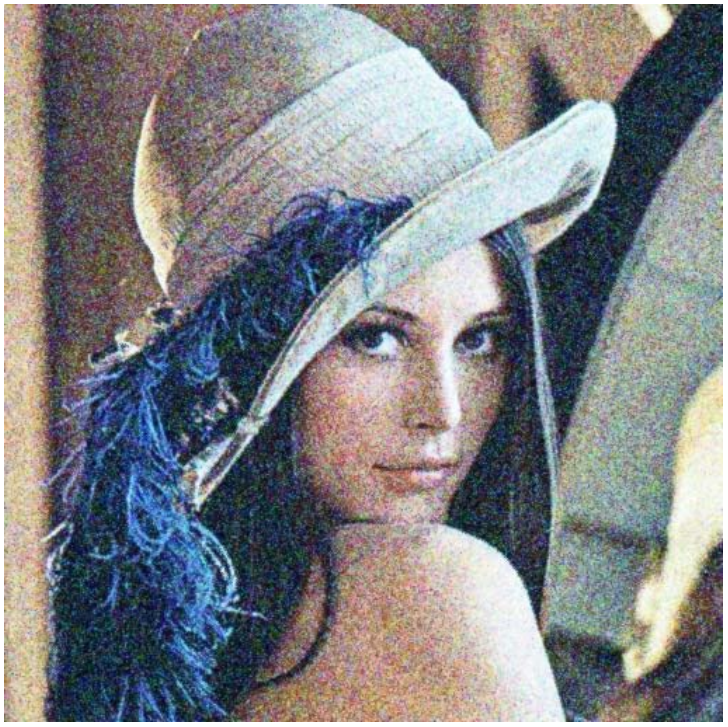
- Main application: Medical image enhancement

Original image

Histogram equalized image

Color Histogram Equalization (1)

- Color histogram modification
  - Hue component is should be preserved.
  - HSV space

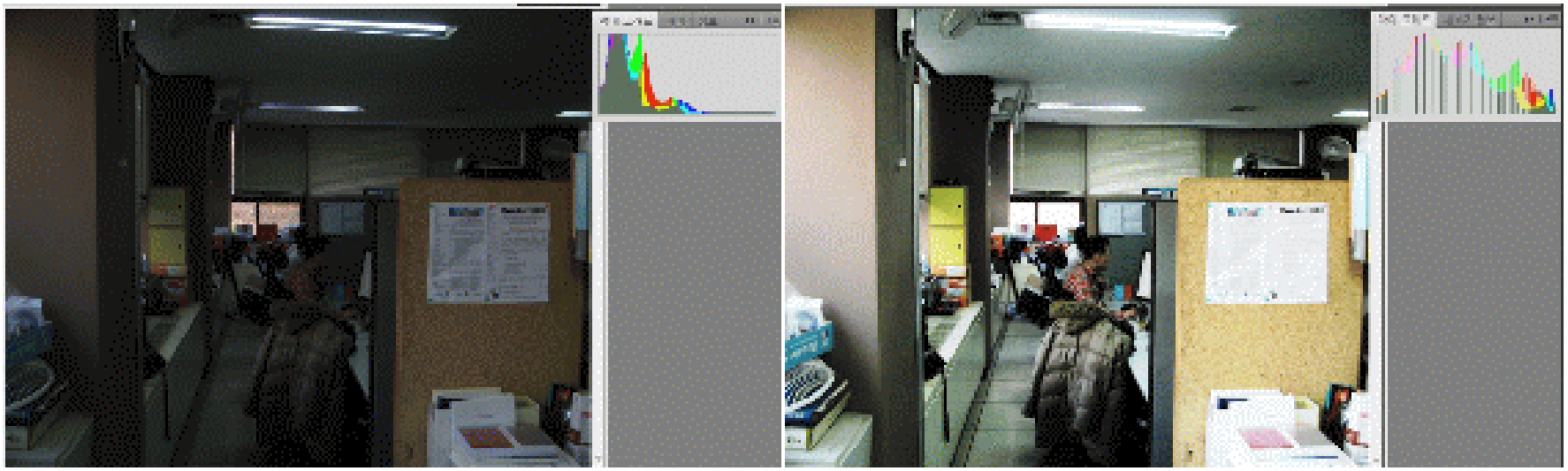


RGB equalization result of noisy image

V in HSV equalization + noise reduction

Color Histogram Equalization (2)

- Reverse lighting compensation



Original image

Histogram equalized image

Color Histogram Equalization (3)

Original Image

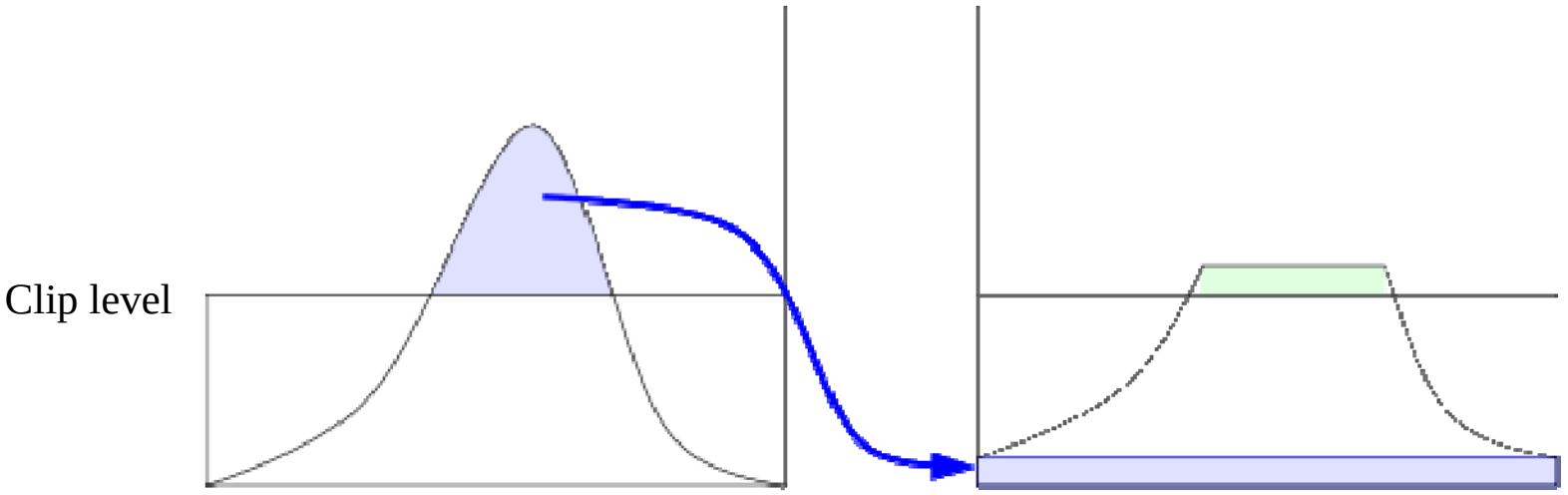
Equalizing V

Equalizing V and S

Equalizing H, S, and V

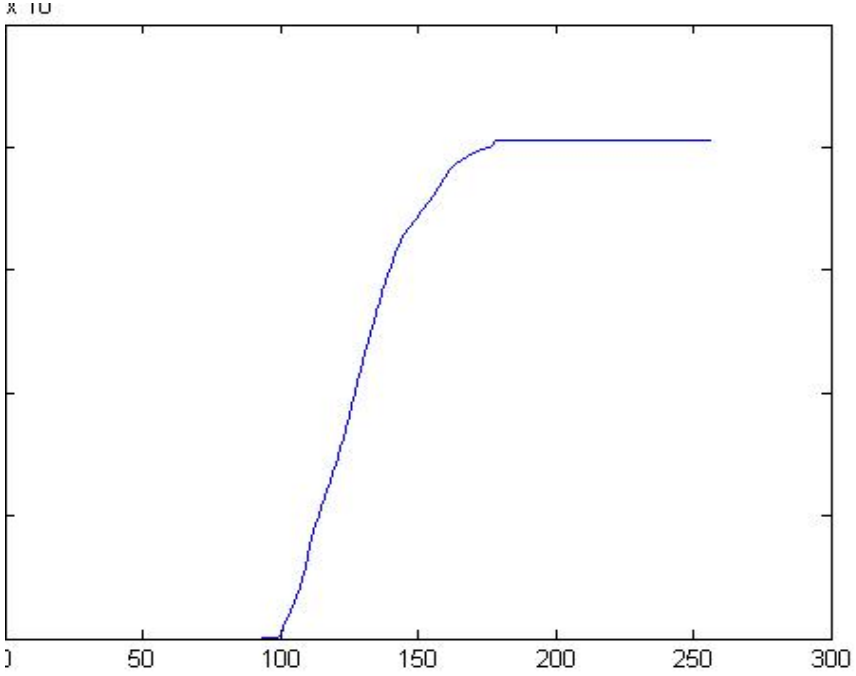
Clipping Histogram Equalization (1)

- Intensity with high probability overemphasizes the contrast.
- Limitation of maximum probability in the histogram
  - Clipping the probability
  - Increasing the frequencies of low histogram by distributing uniformly the clipped probability

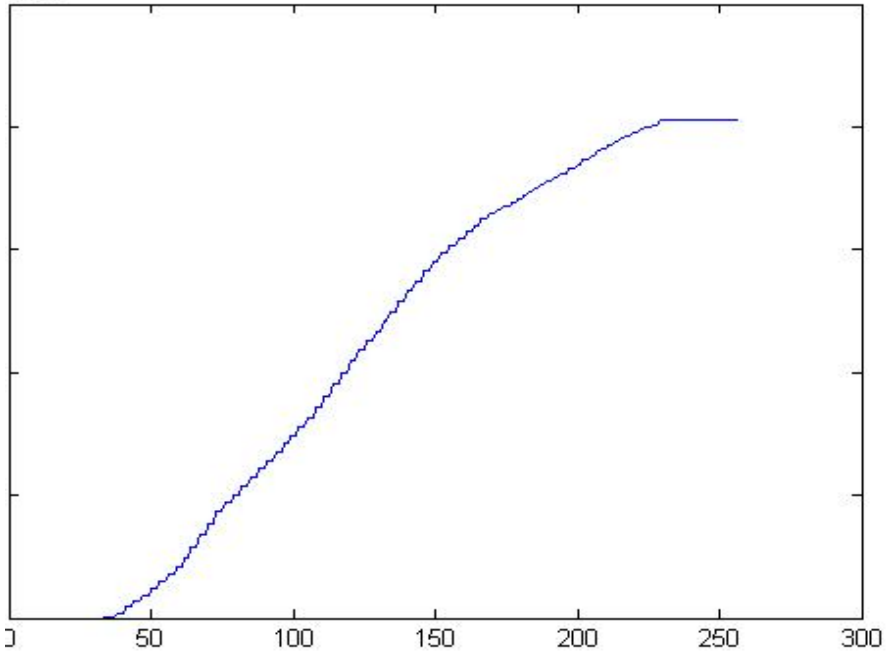


Clipping Histogram Equalization (2)

- Example of clipped histogram



Original CDF



Clipping CDF

Clipping Histogram Equalization (3)

clip level=0.01

clip level=0.1

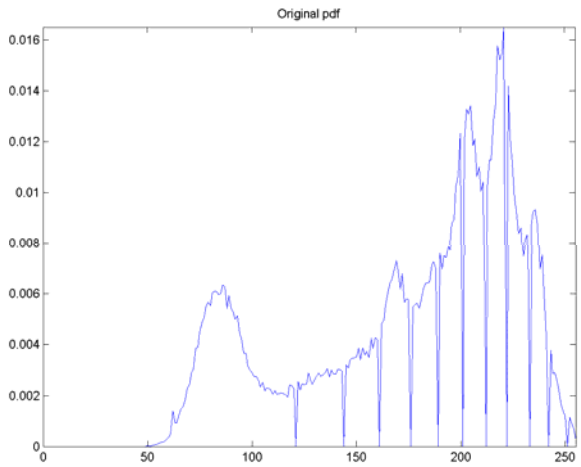
clip level=0.25

clip level=0.5

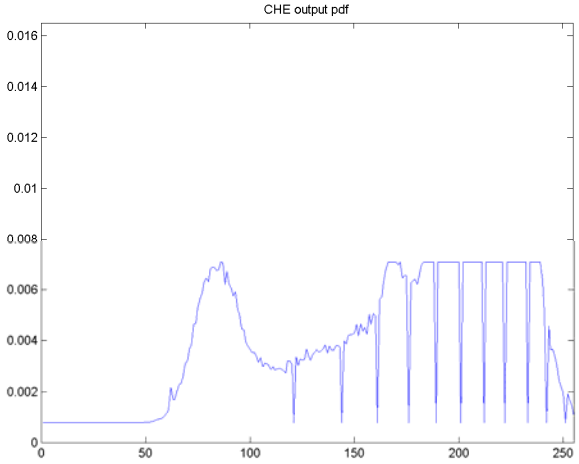
If clip level is too high,
no difference from HE

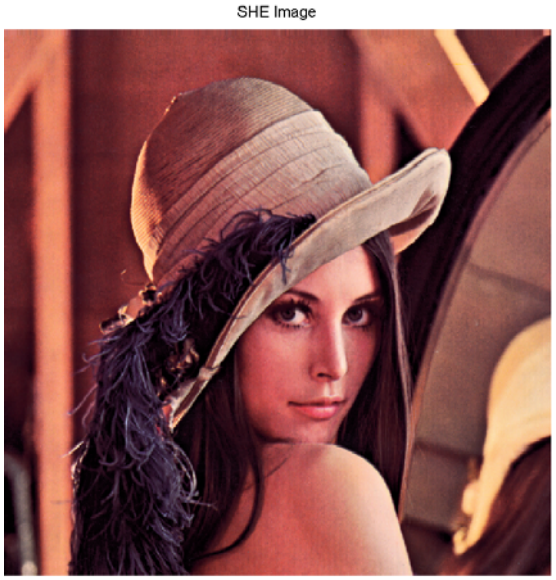
If clip level is too small,
No equlaization

Comparison (1)

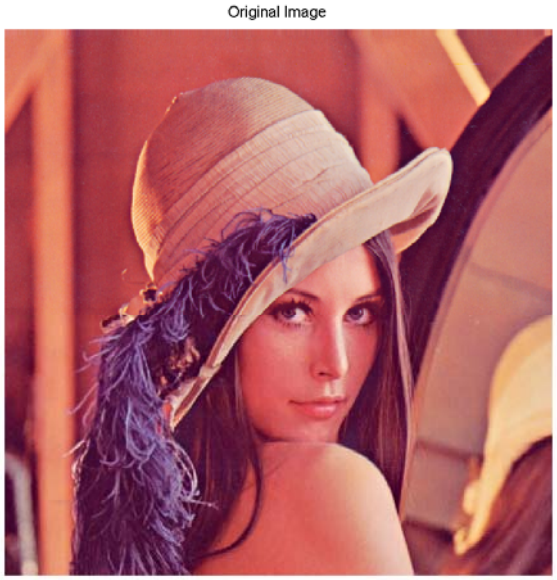


Clipping

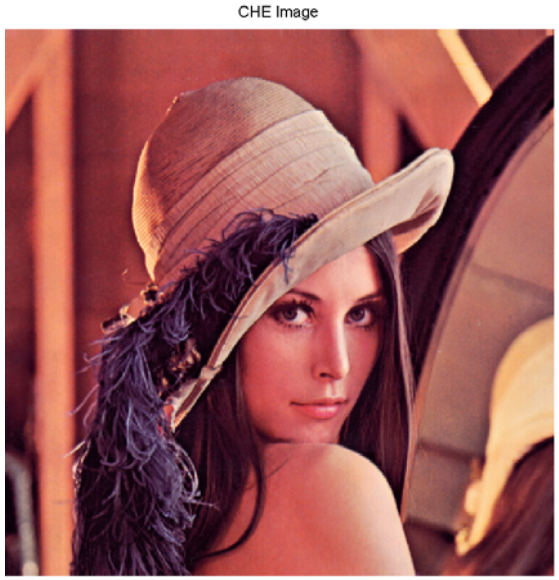




Standard HE (SHE)

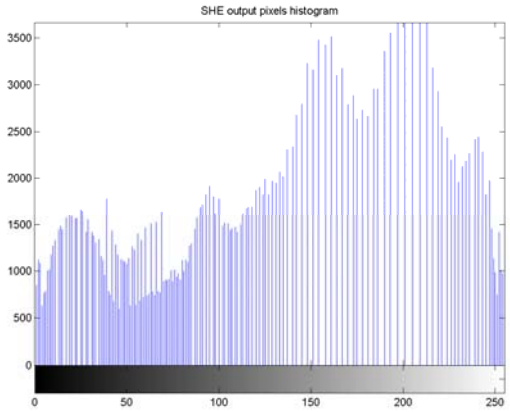


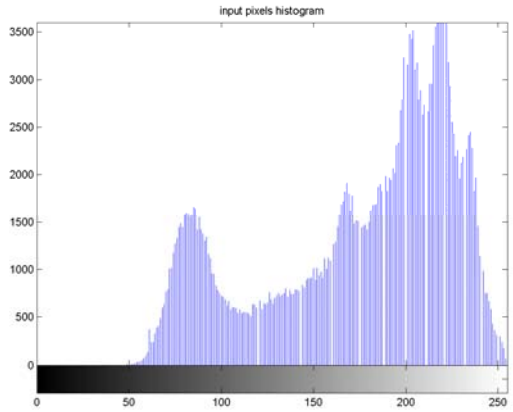
Original image

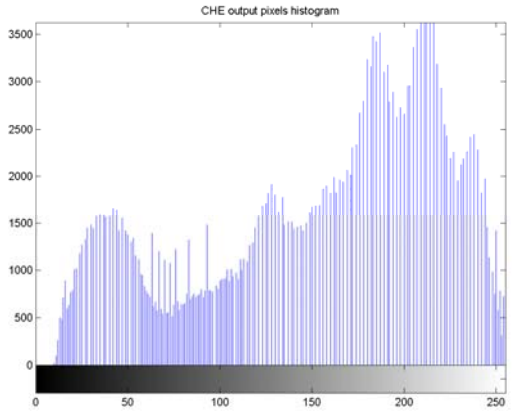


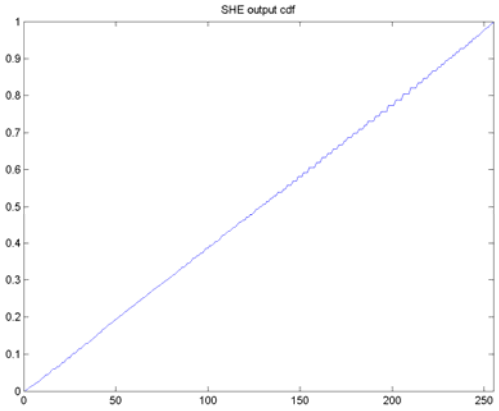
Clipping HE (CHE)

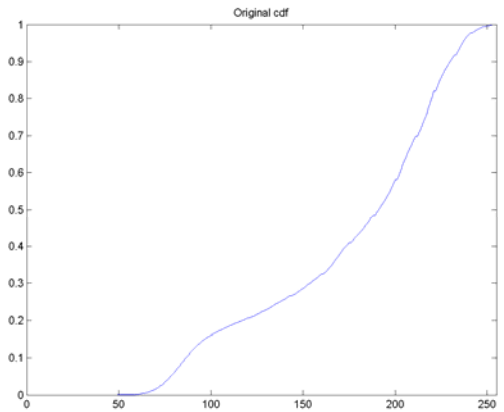
Comparison (2)

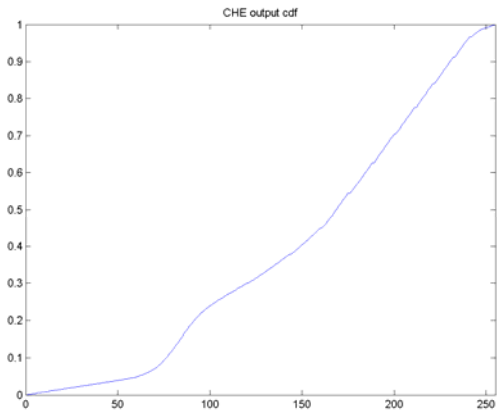










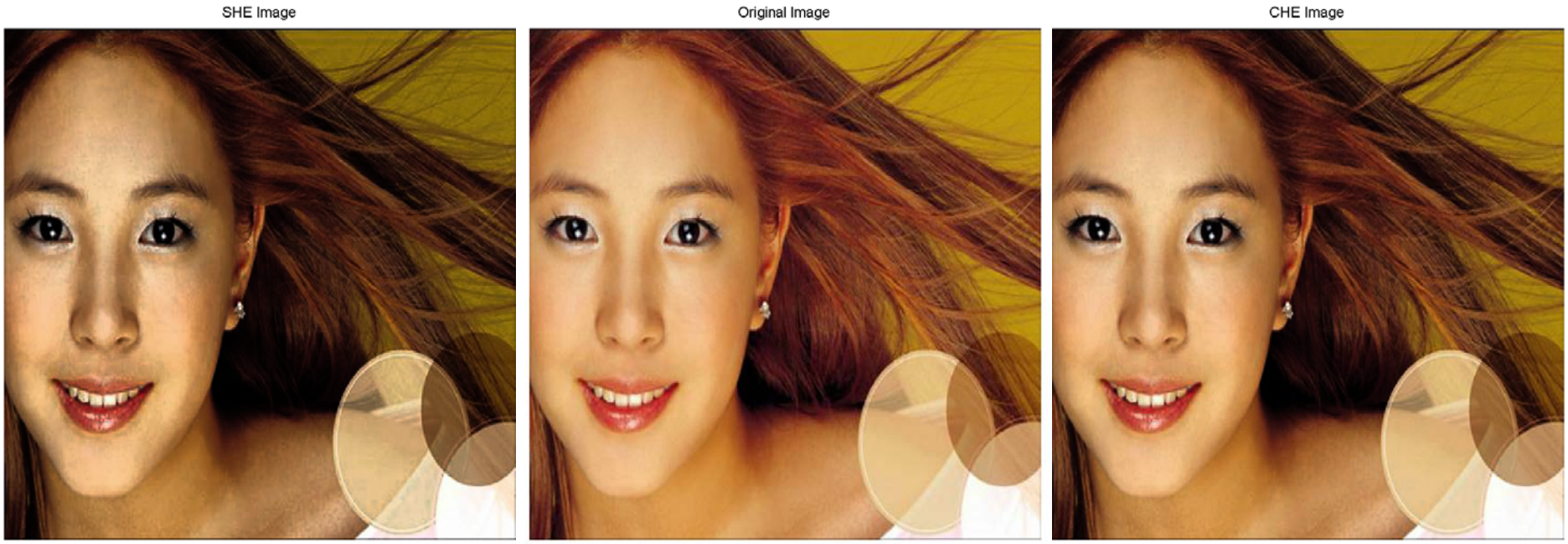


Standard HE image CDF

Original image CDF

Clipping HE (CHE) CDF

Comparison (3)



Standard HE image CDF

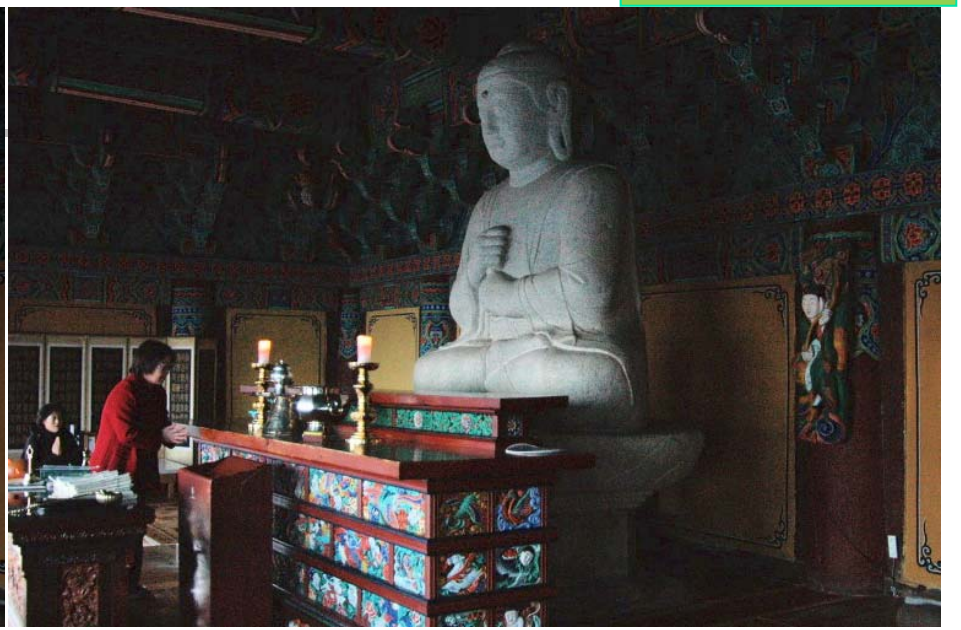
Original image CDF

Clipping HE (CHE) CDF

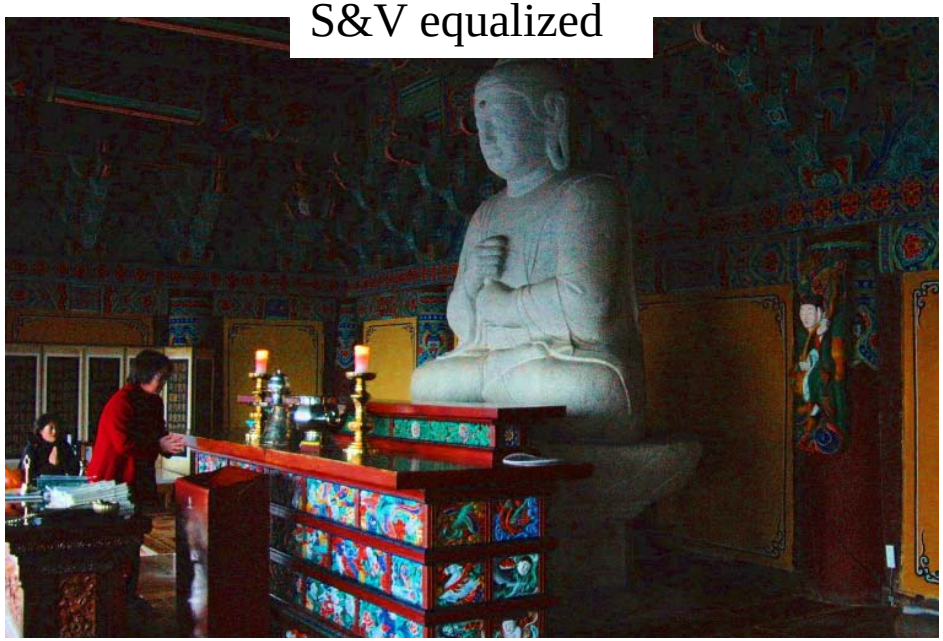
Original

V equalized

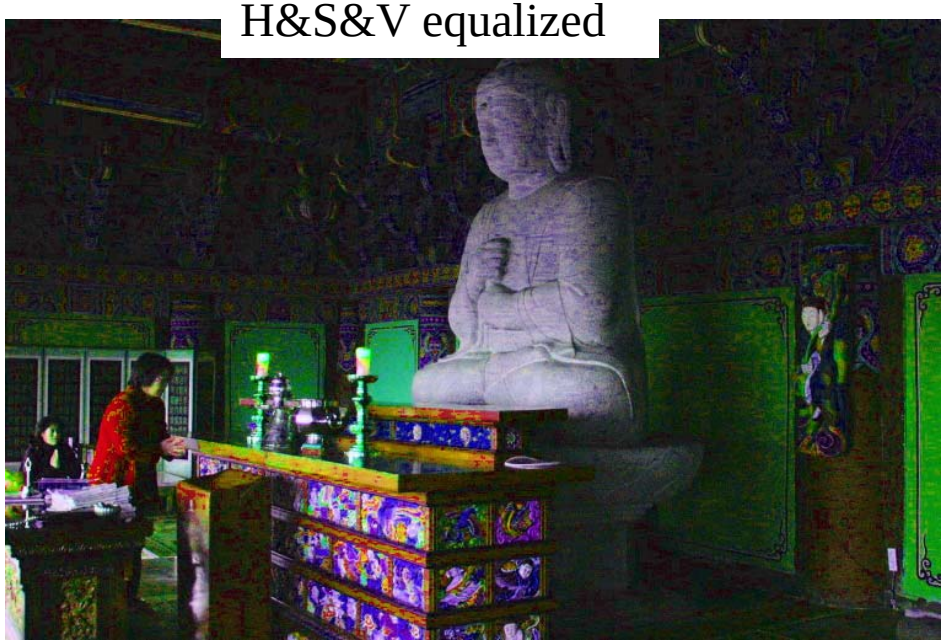
Clip level=0.1



S&V equalized



H&S&V equalized



Original

V equalized

Clip level=0.01

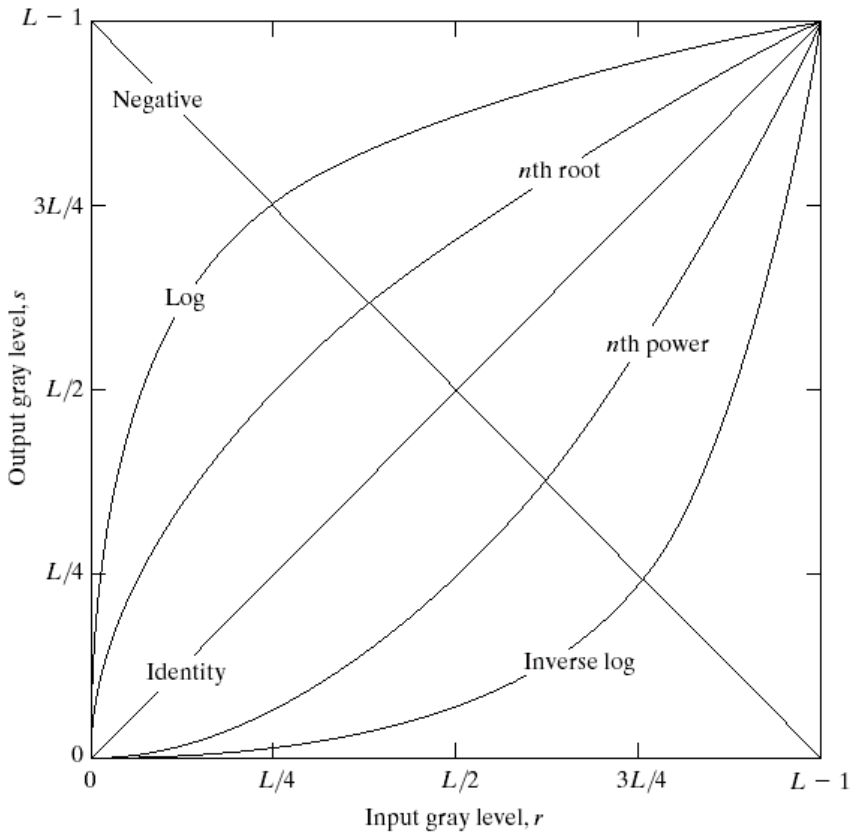
S&V equalized

H&S&V equalized

Gray Level Transformation (1)

- Global transformation of intensity values
  - Not using statistics (histogram)
  - Using a general function

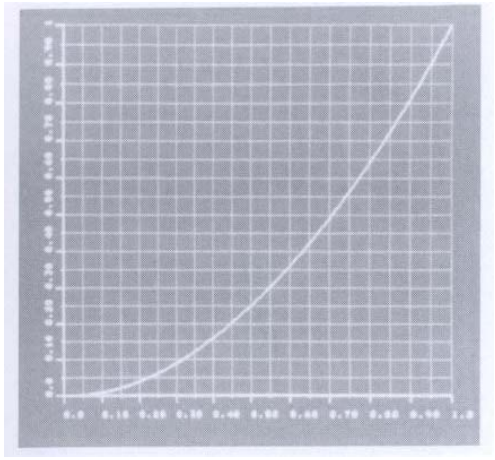
FIGURE 3.3 Some basic gray-level transformation functions used for image enhancement.



Gray Level Transformation (2)

Original image

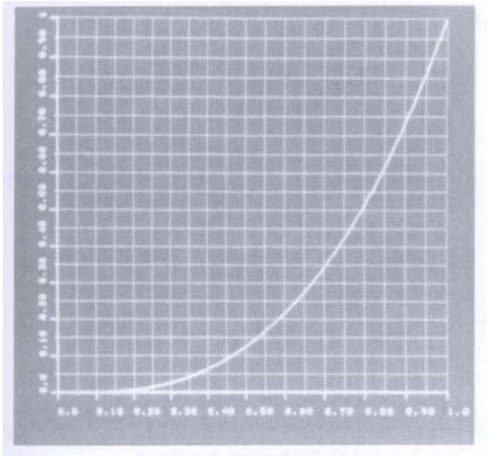
×



Square function

Square output

×



Cube function

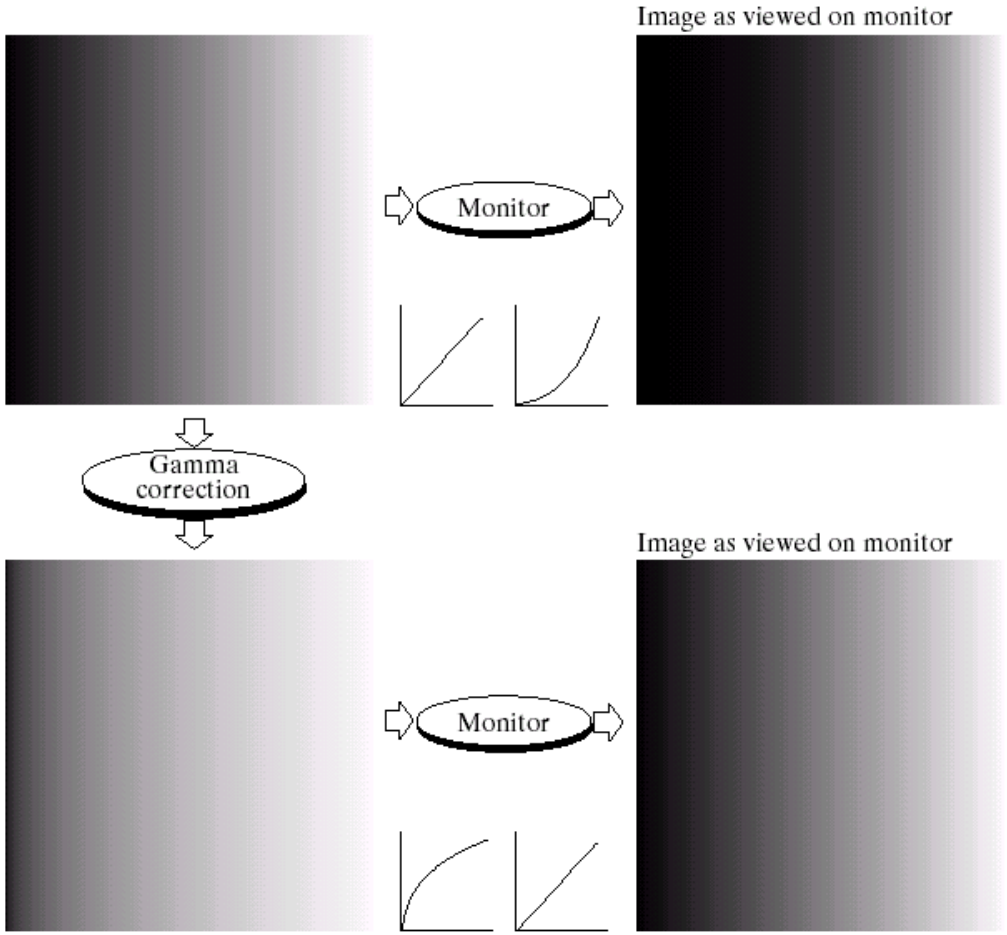
Cube output

Gray Level Transformation (3)

- Gamma correction
  - Compensation for different color/intensity on display

a b
c d

FIGURE 3.7
(a) Linear-wedge gray-scale image. (b) Response of monitor to linear wedge. (c) Gamma-corrected wedge. (d) Output of monitor.



High Pass Filter

Sharpening Images

- Human visual system prefer high contrast and sharp boundaries.
- Emphasis of high-frequency components using High pass filters
- HPF usually exploits 1st and 2nd derivatives
  - 1st order derivative:

$$\frac{\partial f}{\partial x} = f(x+1) - f(x)$$

  - 2nd order derivative:

$$\frac{\partial^2 f}{\partial x^2} = f(x+1) + f(x-1) - 2f(x)$$

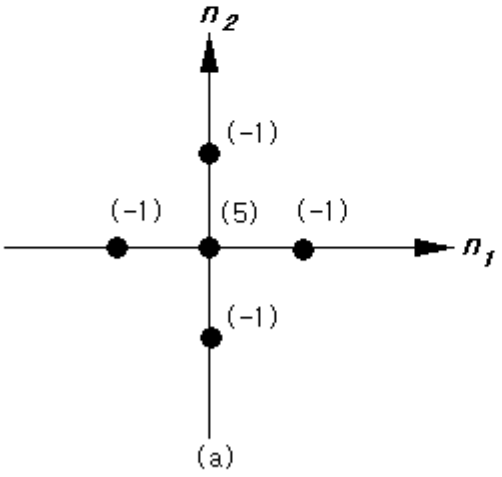
High Pass Filtering (1)

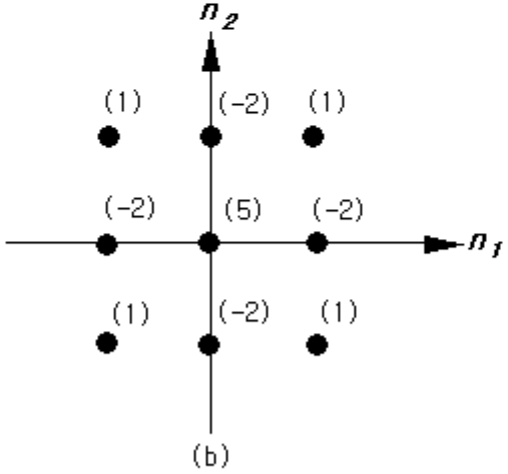
0	-1	0
-1	5	-1
0	-1	0

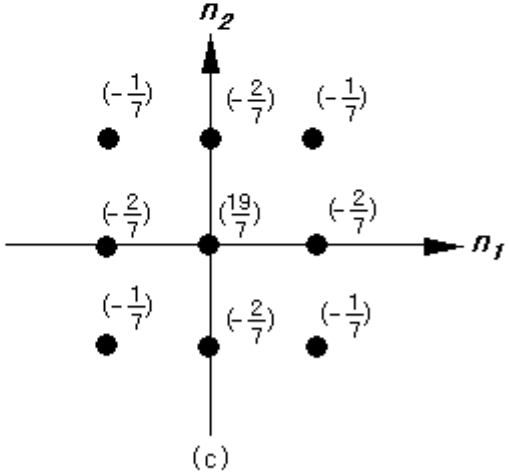
1	-2	1
-2	5	-2
1	-2	1

$\frac{1}{7}\cdot$

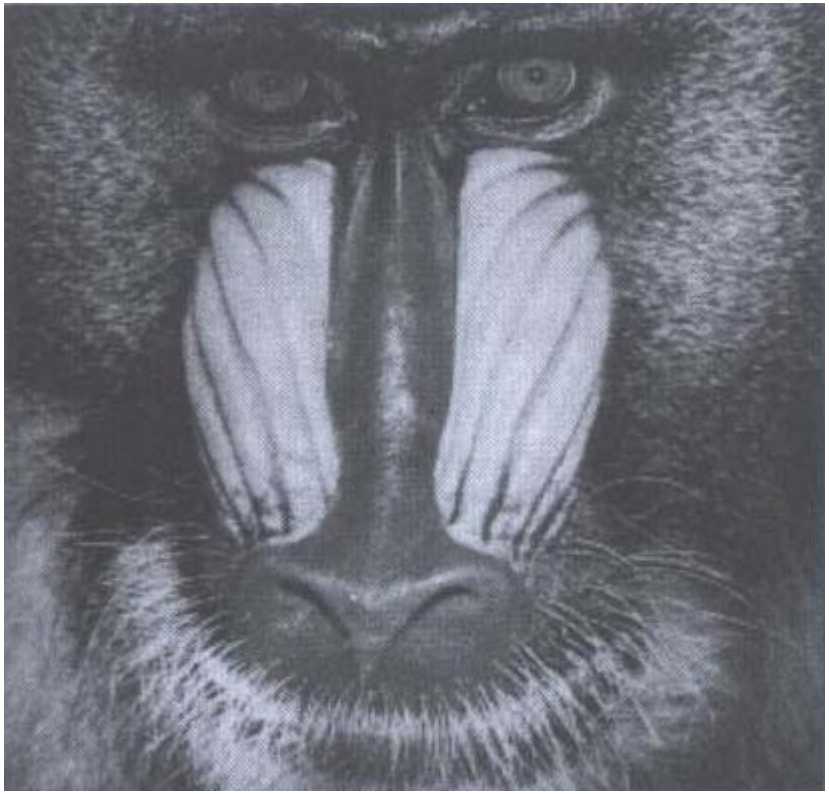
-1	-2	-1
-2	19	-2
-1	-2	-1



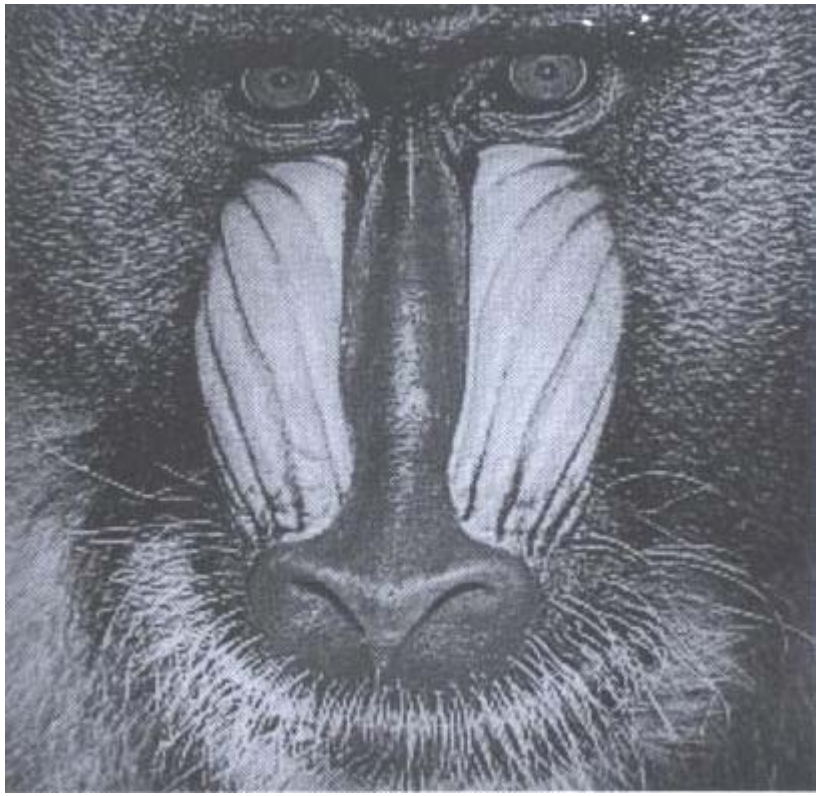




High Pass Filtering (2)



Original image



Highpass filtered image

Unsharp Mask

Laplacian Operator (1)

- 2^{nd} –order Derivatives
  - Finding convex (+ sign) and concave (- sign) geometry

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

$$\begin{aligned}\Delta_x^2 f(i,j) &= \Delta_x f(i+1,j) - \Delta_x f(i,j) \\ &= [f(i+1,j) - f(i,j)] - [f(i,j) - f(i-1,j)] \\ &= f(i+1,j) + f(i-1,j) - 2f(i,j)\end{aligned}$$

$$\Delta_y^2 f(i,j) = f(i,j+1) + f(i,j-1) - 2f(i,j)$$

$$\begin{aligned}\therefore \nabla^2 f(i,j) &= \Delta_x^2 f(i,j) + \Delta_y^2 f(i,j) \\ &= [f(i+1,j) + f(i-1,j) + f(i,j+1) + f(i,j-1)] - 4f(i,j)\end{aligned}$$

Laplacian Operator (2)

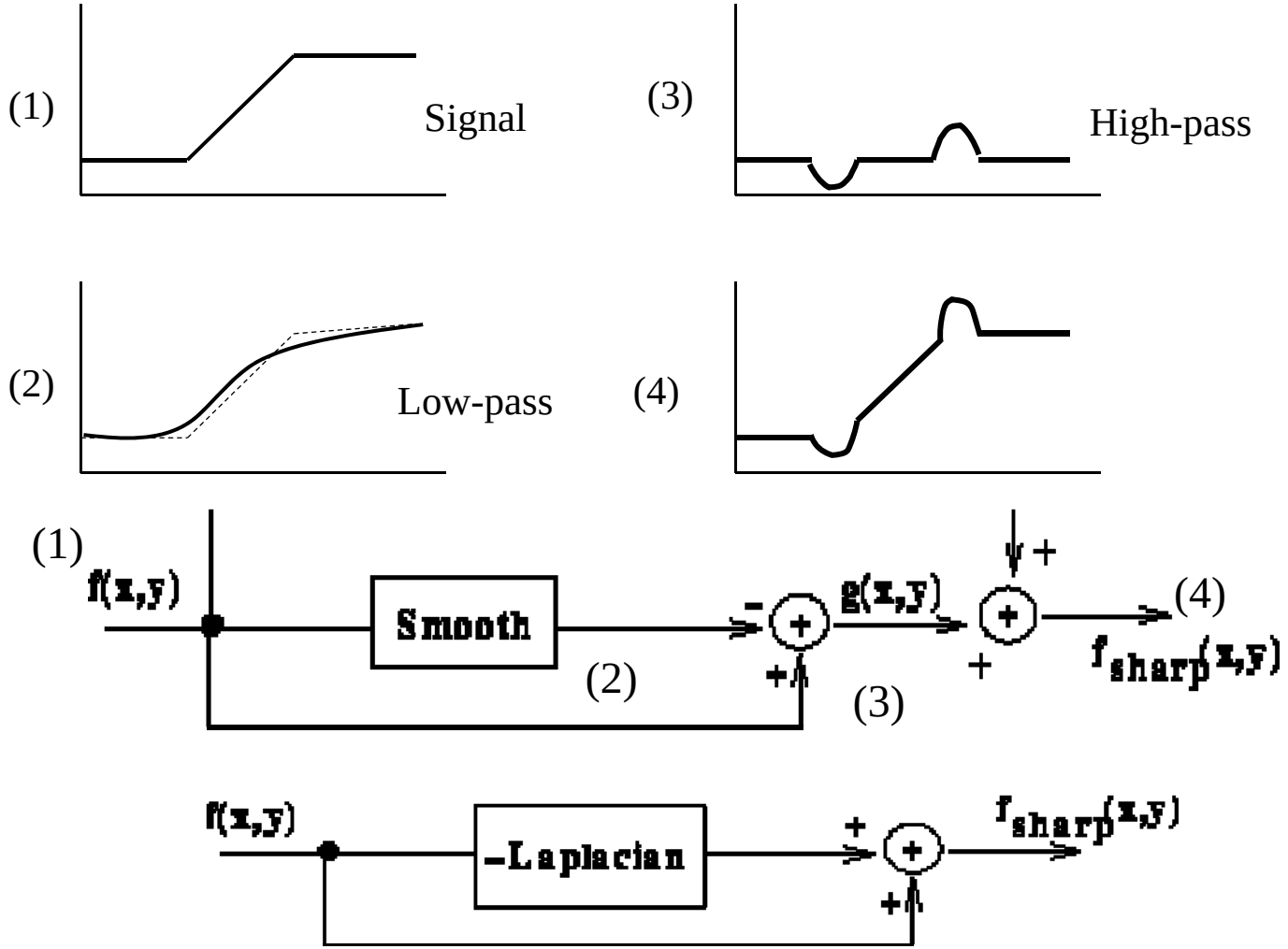
Some examples of Laplacian operators (filters)

$$H_1 = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \quad H_2 = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix} \quad H_3 = \begin{bmatrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{bmatrix}$$

Most popular

Unsharp masking

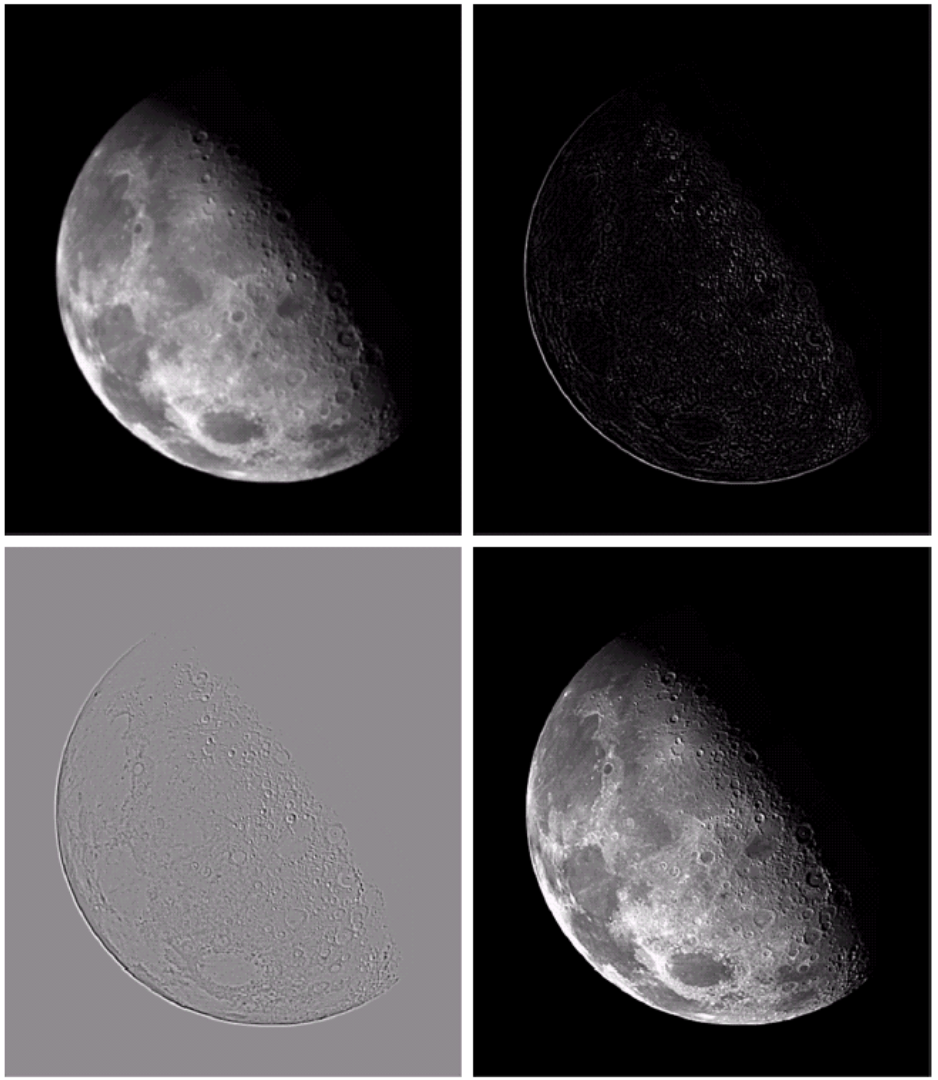
- Most popular image sharpening algorithm



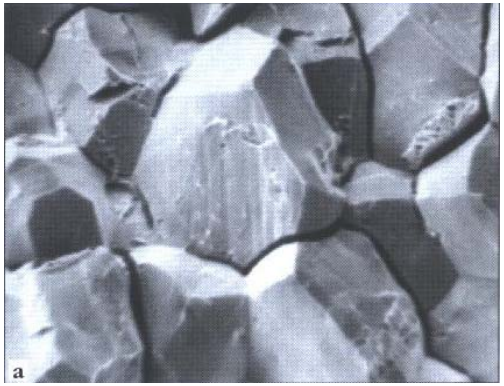
Unsharp Masking Example (1)

a b
c d

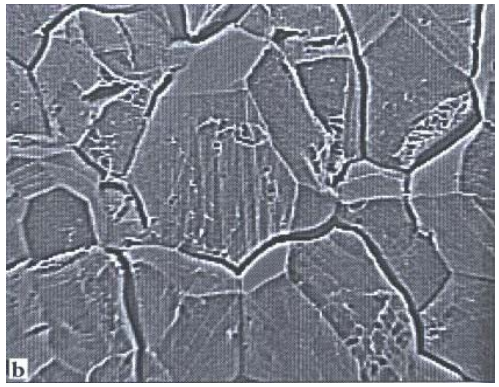
FIGURE 3.40
(a) Image of the North Pole of the moon.
(b) Laplacian-filtered image.
(c) Laplacian image scaled for display purposes.
(d) Image enhanced by using Eq. (3.7-5).
(Original image courtesy of NASA.)



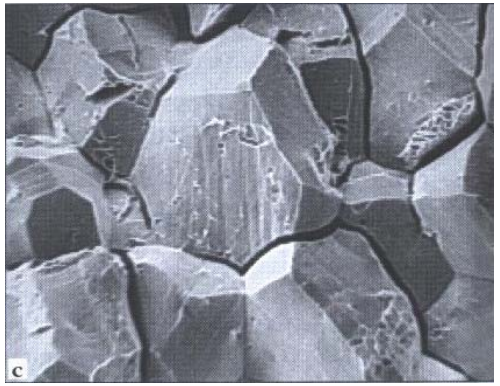
Unsharp Masking Example (2)



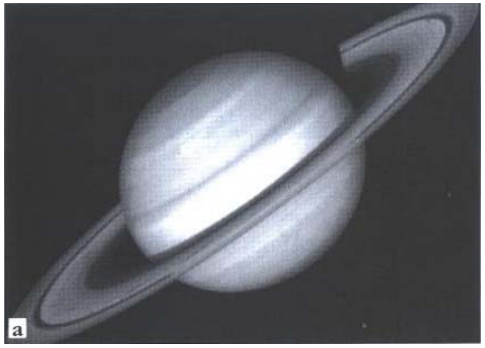
Original SEM image



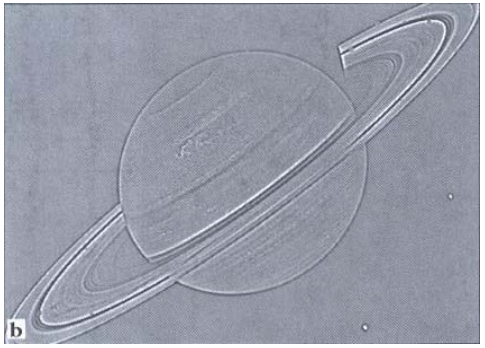
Laplacian operator



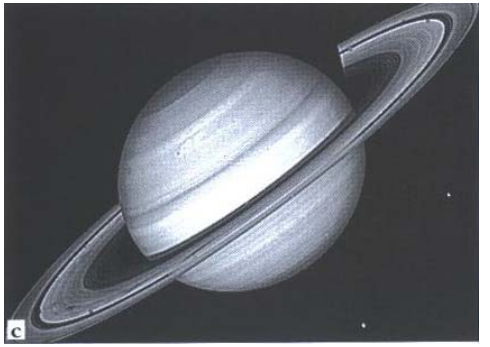
Subtraction of the Laplacian from the original



Original image



Laplacian operator



Subtraction of the Laplacian from the original

Unsharp Masking Example (3)

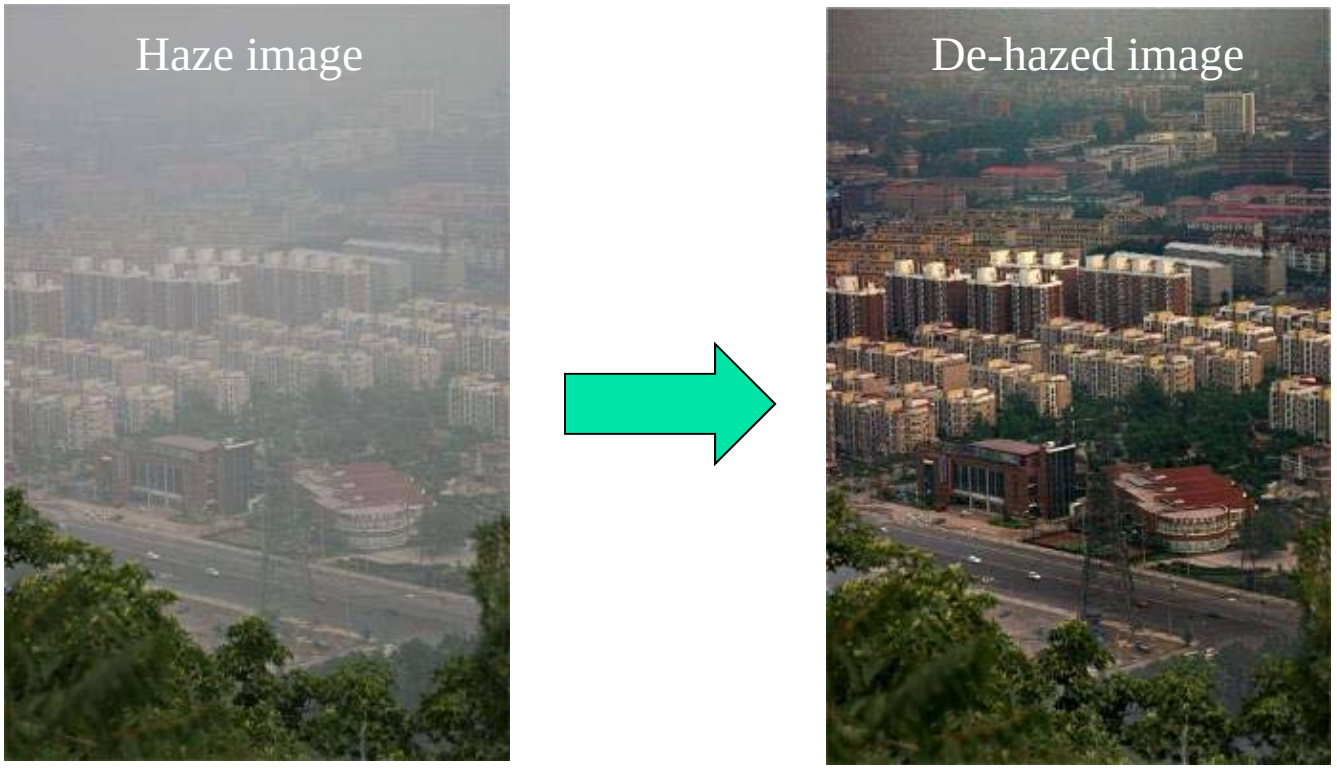
Original Image

Unsharp Masking

Fog (Haze) Removal

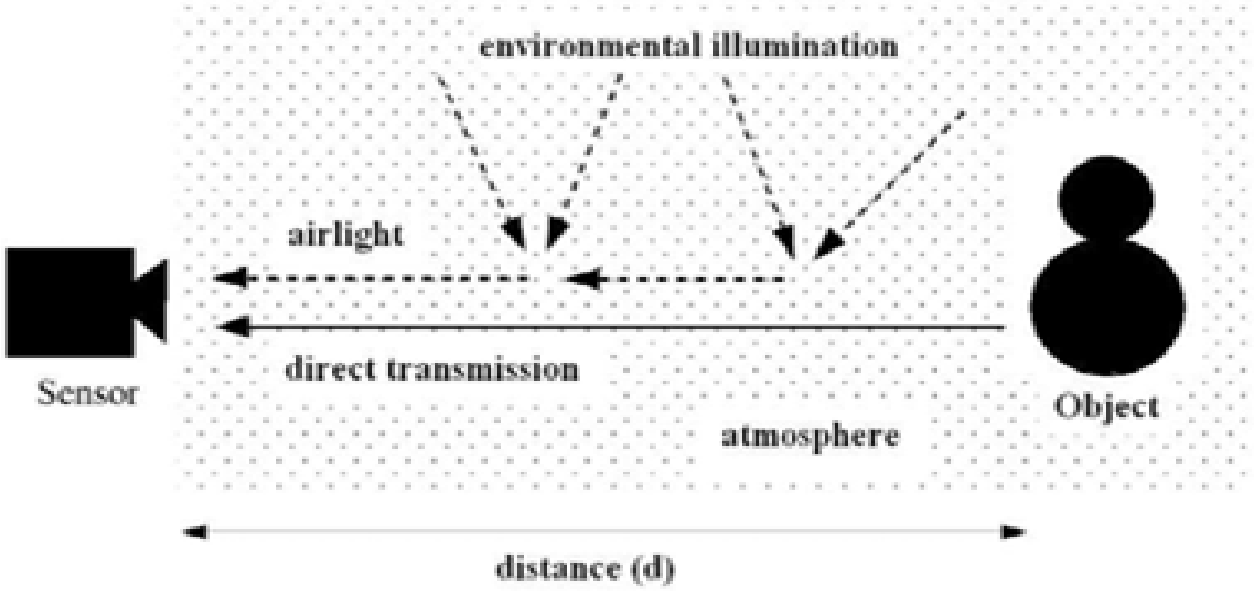
Introduction (1)

- What is haze removal ?
  - Color restoration
  - Contrast enhancement
  - Improving object detection/recognition…



Introduction (2)

- Optical observation model



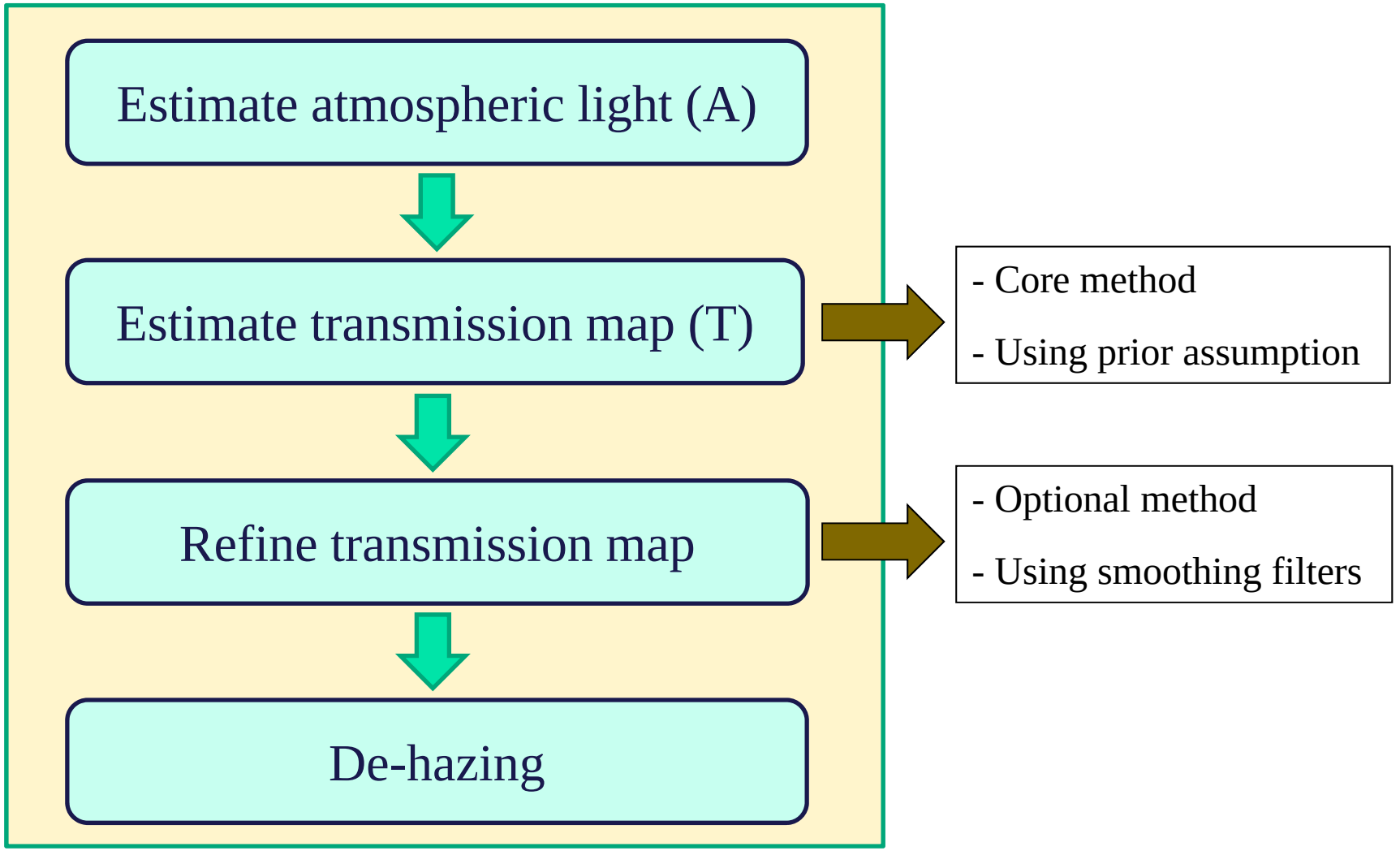
$$I(x) = J(x)t(x) + A(1 - t(x))$$

$$t(x) = e^{-\beta d(x)}$$

$J(x)$: scene radiance
$I(x)$: observed intensity
A : global atmospheric light
$t(x)$: transmission

Introduction (3)

- General process

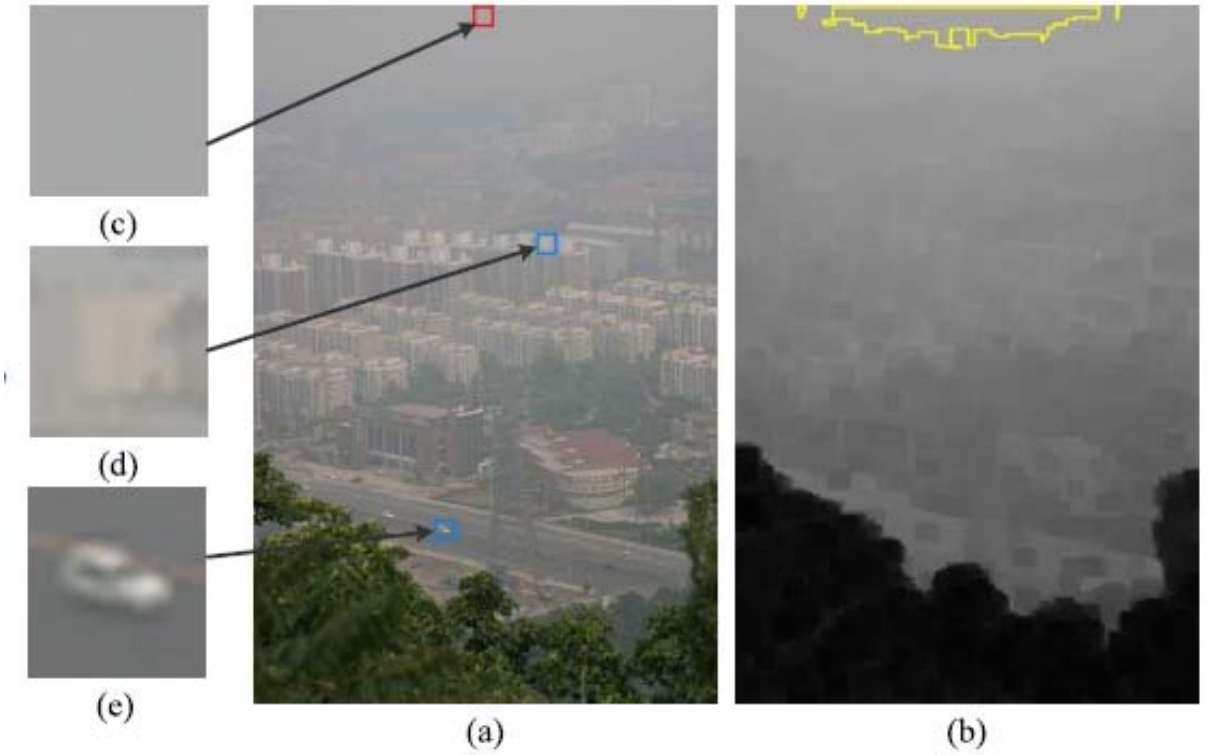


Related Works

- Main category
  - How to estimate the transmission map ?
- Distance-based approaches
  - Estimate the distance
  - Using multiple cameras, sensors…
  - Impractical !!!
- Single image based approaches
  - Modeling the transmission map directly in a single image
  - Dark channel prior (DCP)
  - Contrast enhancement (CE)

Estimation of atmospheric light

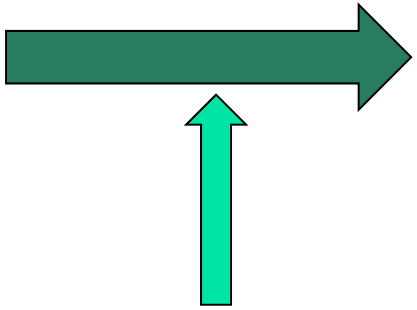
- Usually, pick the top brightest pixels in the block average
  - Achromatic and upper region



Refinement of Transmission Map

- Example

Input transmission map



Output transmission map

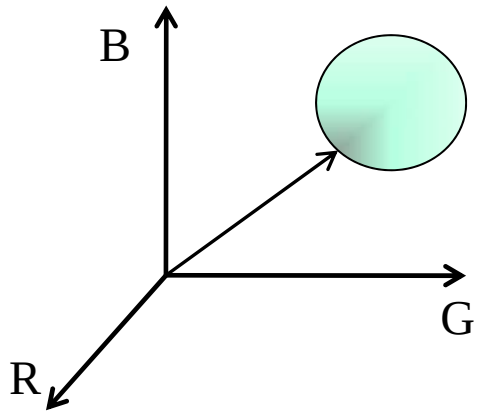
Guided (input) image

Refinement of Transmission Map

- Using smoothing filters
  - Image matting
    - Estimate alpha map
    - A. Levin, D. Lischinski, and Y. Weiss, “A closed form solution to natural image matting,” *proc. of CVPR*, 2006.
  - Cross bilateral filtering
    - Applying bilateral filter to transmission map
  - Guided image filtering
    - Similar to bilateral filter for refining the transmission map
    - K. He, J. Sun, and X. Tang, “Guided image filtering,” *Proc. of ECCV*, pp. 1-14, 2010.
  - MRF models
    - Smoothness prior of transmission map

Dark Channel Prior

- Basic observation
  - For haze-free or fog-free images,
  - One of color channels for is almost close to zero for a pixel in the local block.
- Haze/fog → bright gray-color
  - RGB channels similar to haze colors have high values.



Bright gray-tone = haze/fog

Dark Channel Prior

- Proper examples
  - Good for colorful objects
- Limitations
  - Gray and dark objects
  - Causing color saturation

컬러영상

Dark channel 값 표시 영상

Dark Channel Prior

- Basic formulation of DCP
  - Estimate transmission parameter (t)

$$J^{dark}(x) = \min_{c\in\{r,g,b\}} \left(\min_{y\in\Omega(x)} \left(J^c(y) \right) \right) \qquad I(x) = J(x)t(x) + A(1-t(x))$$

$$\min_{c\in\{r,g,b\}} \left(\min_{y\in\Omega(x)} \left(\frac{I^c(y)}{A^c}(y) \right) \right) = \tilde{t}(x) \min_{c\in\{r,g,b\}} \left(\min_{y\in\Omega(x)} \left(\frac{J^c(y)}{A^c}(y) \right) \right) + (1-\tilde{t}(x))$$

$$\min_{c\in\{r,g,b\}} \left(\min_{y\in\Omega(x)} \left(\frac{J^c}{A^c}(y) \right) \right) = 0 \quad \text{for haze-free}$$

$$\tilde{t}(x) = 1 - \min_{c\in\{r,g,b\}} \left(\min_{y\in\Omega(x)} \left(\frac{I^c(y)}{A^c}(y) \right) \right)$$

Transmission parameter

$$\tilde{t}(x) = 1 - w \min_{c} \left(\min_{y\in\Omega(x)} \frac{I^c(y)}{A^c} \right)$$

Transmission parameter with weight *w*

Results of Dark Channel Prior

- Experimental results

Figure 7. Haze removal results. Top: input haze images. Middle: restored haze-free images. Bottom: depth maps. The red rectangles in the top row indicate where our method automatically obtains the atmospheric light.

Results of Dark Channel Prior

- Depth map refinement

Input image

De-hazed image

DCP transmission map

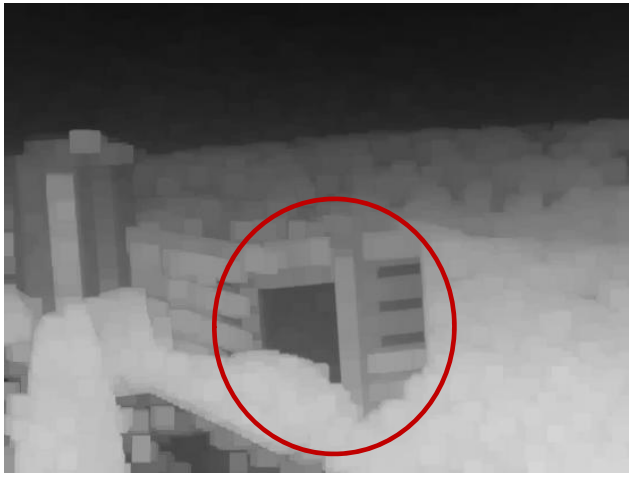
Refined DCP transmission map

Results of Dark Channel Prior

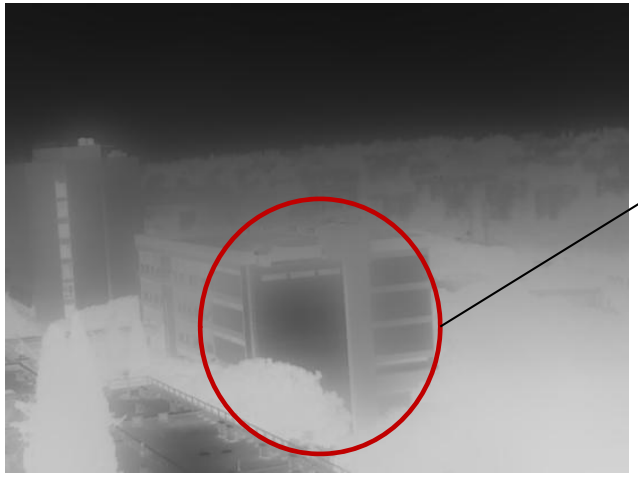
- Experimental results (limitation)

Input image

De-hazed image



DCP transmission map



Refined DCP transmission map