Adaptive and integrated neighborhood-dependent approach for nonlinear enhancement of color images

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Abstract

- Objective
  - Enhancement of digital image captured under low illumination conditions
- Proposed algorithm
  - Adaptive and integrated neighborhood dependent approach for nonlinear enhancement (AINDANE)
    - Adaptive luminance enhancement
      - Global intensity transformation with nonlinear transfer function (dynamic range compression)
    - Adaptive contrast enhancement
      - Tune of the intensity of each pixel with neighbor pixels
  - Two procedure for flexibility and easier control

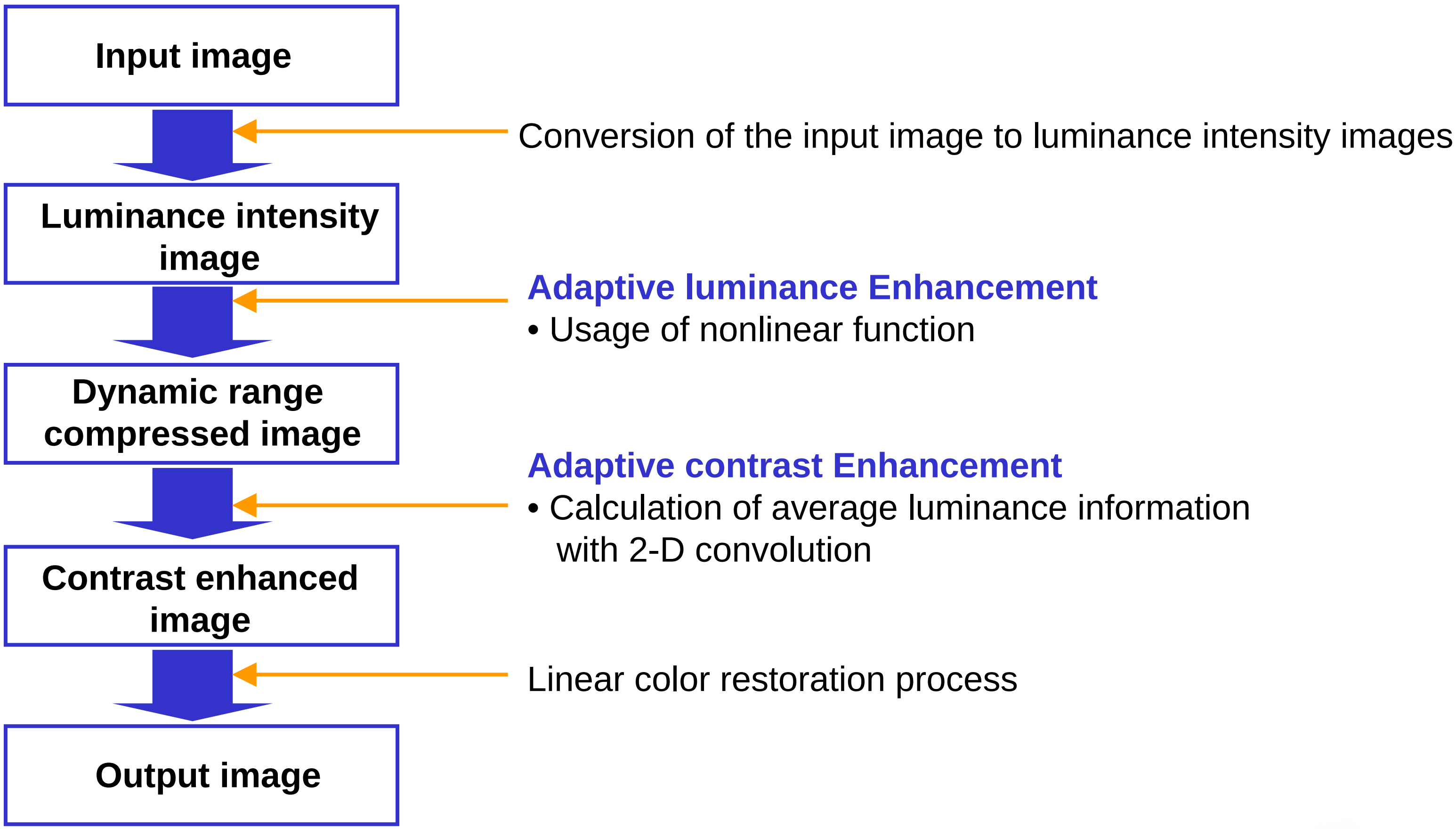
Introduction

- Better performance of human vision
  - Perception of more than six order magnitude
  - Accommodation of different levels of radiance by controlling the size of pupils
  - Dynamic range compression via the lateral processing at the retinex level
  - Dynamic range processing with the visual cortex

- Method for modeling of human visual system (HVS)
  - Dynamic range compression

- Adaptive and integrated neighborhood dependent approach for nonlinear enhancement (AINDANE)
  - Two independent procedure
    - Adaptive luminance enhancement
      - Treatment of luminance information
      - Dynamic range compression
    - Adaptive contrast enhancement
      - Preservation of details
      - Approximation of the tonality with the original image
  - Properties
    - Flexibility and capability to turn and control of the image enhancement

– Diagram of the whole procedure



Related work

- Retinex-based algorithms
  - Properties
    - Management of dynamic range compression and color constancy
    - Computational complexity
  - MSRCR (Multi-scale retinex for color restoration)
    - Logarithmic compression and spatial convolution
    - Time consuming, nonlinear color restoration causing the unnatural image result, and artifacts at the boundaries
  - LDNE (Luma-dependent nonlinear enhancement)
    - Luminance based multi-scale retinex algorithm for time reducing

- Histogram equalization (HE) algorithms
  - Histogram equalization
    - Poor result image with bimodal histogram
  - AHE (Adaptive histogram equalization)
    - HE within a window
    - Noise enhancement and ring artifacts
  - Contrast limiting AHE
    - Clip of histogram level
    - Undesired noise amplification and boundary artifacts
  - Multi-scale AHE
  - Wavelet-based MAHE
    - Adaptively based on spatial-frequency properties

- Tone reproduction operators
  - Histogram adjustment
    - Usage of population of local adaptation of luminance
    - Lack of contrast enhancement
  - Tone mapping with neighborhood dependent
    - Similar with MSRCR
    - Halo artifacts
  - Low-curvature image simplifier (LCIS)
    - Overemphasis of details, computational complexity, and many parameters

AINDANE Algorithm

- Adaptive luminance enhancement
  - Conversion of the luminance information
    - Method in standard NTSC (National Television Standards Committee)

$$I(x,y) = \frac{76.245\, I_R(x,y) + 19.685\, I_G(x,y) + 29.071\, I_B(x,y)}{255} \quad (1)$$

where $I_R(x,y)$, $I_G(x,y)$, and $I_B(x,y)$ are R, G, and B value (8-bit)

  - Normalization

$$I_n(x,y) = \frac{I(x,y)}{255} \quad (2)$$

– Enhancement of luminance intensity

- Dynamic range compression

$$I_n^{'} = \frac{I_n^{(0.75z+0.25)} + (1 - I_n)0.4(1-z) + I_n^{(2-z)}}{2} \quad (3)$$

where z is the image dependent parameter , and
L is the intensity level corresponding to a CDF of 0.1

$$z = \begin{cases} 0 & for\ L \le 50 \\ \dfrac{L-50}{100} & for\ 50 < L \le 150 \\ 1 & for\ L > 150 \end{cases}$$

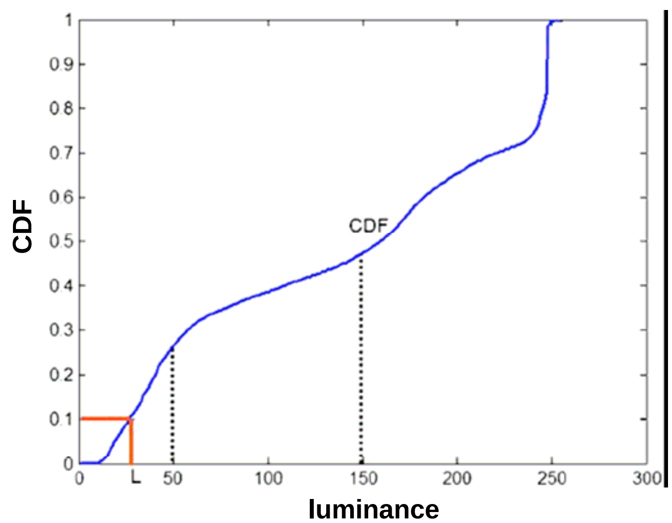


Fig 1. CDF of an intensity image

- Property of the transfer function
  - Large enhancement of low luminance
  - Appropriate dynamic range compression
  - Various form depended on the parameter, z

$$I_n' = \frac{I_n^{(0.75z+0.25)} + (1-I_n)0.4(1-z) + I_n^{(2-z)}}{2}$$

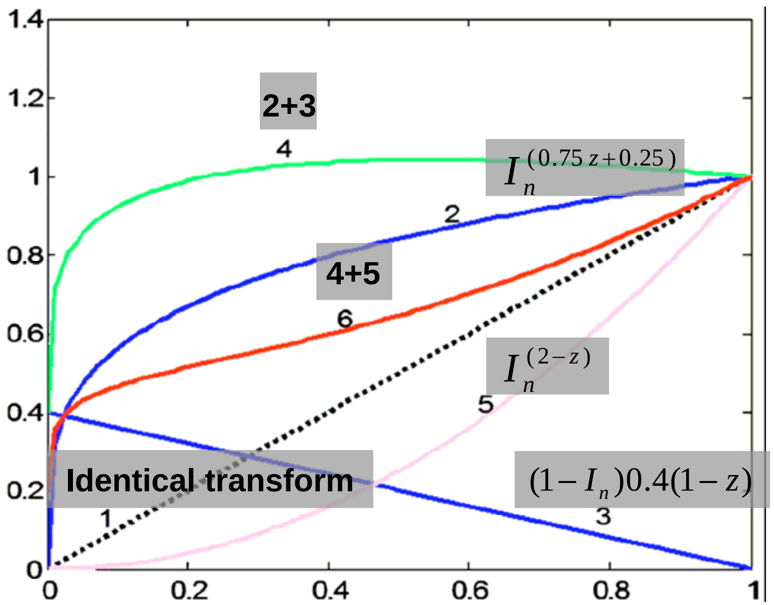


Fig 2. Nonlinear transfer function

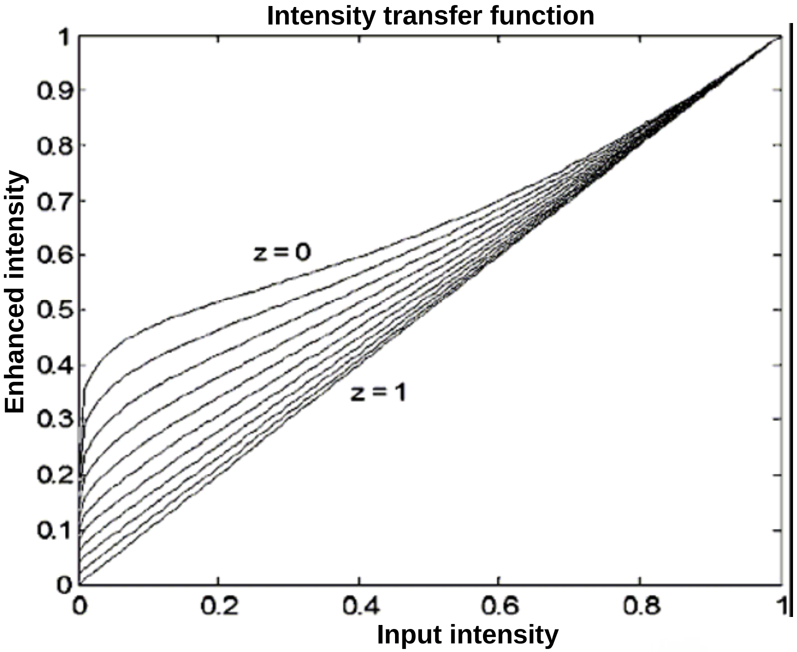


Fig 3. Nonlinear transfer function with z

- Adaptive contrast enhancement
  - Necessity
    - Gray out of the image during enhancement of luminance intensity
  - Disadvantage of normal contrast enhancement technique
    - Significantly expanded
    - Poor result between pixels which have small difference
  - Surrounding pixel (neighborhood) dependent contrast enhancement technique
    - Enhancement of picture contrast and fine details with preserving image quality
    - Different output with pixels which have the same value
      - Booster with darker surround
      - Lower with brighter surround

– Procedure

- Gaussian kernel
  - Closeness with HVS

$$G(x,y) = K \exp\left[\frac{-(x^2+y^2)}{c^2}\right] \tag{4}$$

where c is the scale or Gaussian surround space constant, and

$$\iint K \exp\left[\frac{-(x^2+y^2)}{c^2}\right] dxdy = 1 \tag{5}$$

- 2-D discrete spatial convolution
  - Average of neighborhood

$$I_{conv}(x,y) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} I(m,n) G(m+x, n+y) \tag{6}$$

- Center-surround contrast enhancement
  - Contents
    - » Comparison between center pixel value and convolution result
    - » Pull up with higher center pixel value than average and vice versa
  - Pixel intensity after contrast enhancement

$$S(x, y) = 255\, I_n^{'}(x, y)^{E(x,y)} \qquad (7)$$

$$E(x,y) = r(x,y)^p = \left[\frac{I_{conv}(x,y)}{I(x,y)}\right]^p \qquad (8)$$

where $r(x,y)$ is the ratio , and
p is an image dependent parameter to tune the contrast process,

$$p = \begin{cases} 3 & for\ \sigma \le 3 \\ \dfrac{27 - 2\sigma}{7} & for\ 3 < \sigma < 3 \\ 1 & for\ \sigma \ge 3 \end{cases}$$

where σ is the global standard deviation

- » Linear relationship between p and σ based on experiments
- » User set of p to adjust the contrast enhancement process
- » σ as the contrast level of the original intensity image

– Contrast enhancement curve with various E

» Larger $I_n^{'}(x,y)^{E(x,y)}$ than $I_n^{'}(x,y)$ if $E(x,y)$ is less than 1 ($r(x,y) < 1$)

» Smaller $I_n^{'}(x,y)^{E(x,y)}$ than $I_n^{'}(x,y)$ if $E(x,y)$ is less than 1 ($r(x,y) > 1$)

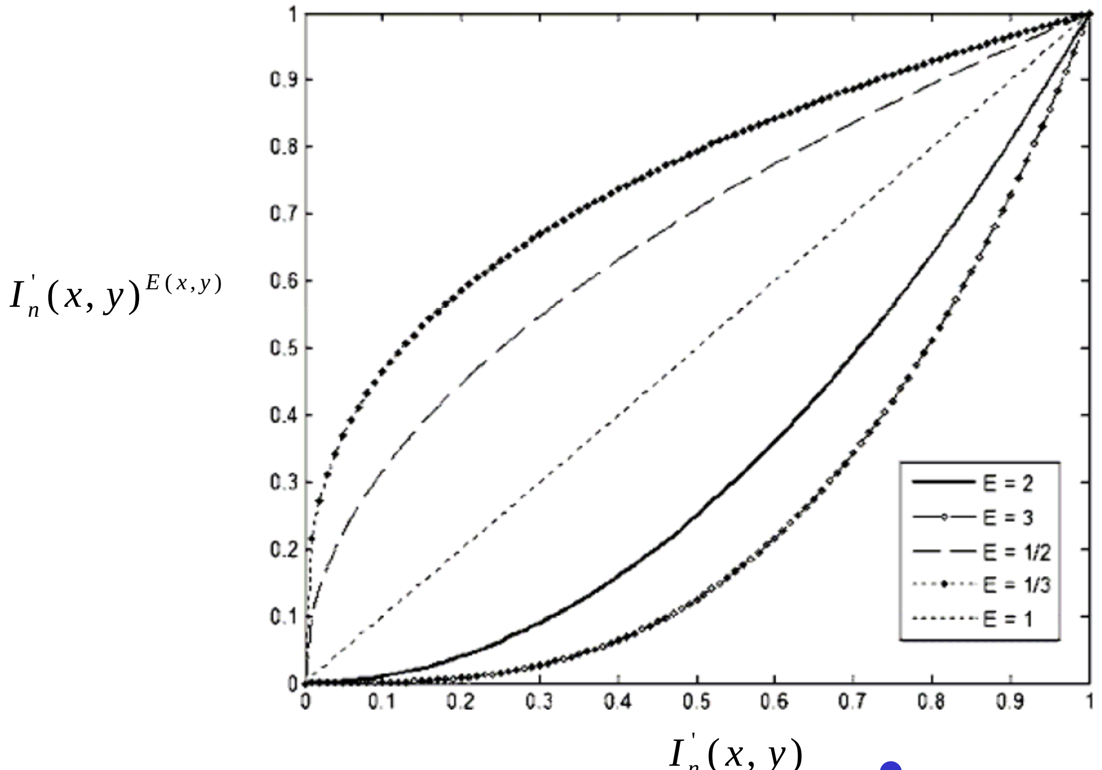


Fig 4. Intensity transformation for contrast enhancement

- Multi-scale convolution for better perfermance
  - Same conception as MSR
    - Small scale for nearest neighbor pixel luminance information
      - » Local contrast or fine details
      - » 1 to 5% of the image size
    - Large scale for the whole luminance information in an image
      - » Smooth and natural looking
      - » 25 to 45% of the image size
    - Medium scale for both luminance information
      - » 10 to 15
  - Properties
    - Calculation of more complete information on the luminance
    - Time consuming with computational complexity

- Equations for Multi-scale convolution

$$G_i(x, y) = K \exp\left[\frac{-(x^2 + y^2)}{c_i^{\,2}}\right] \tag{9}$$

$$I_{conv,i}(x, y) = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} I(m, n) G_i(m + x, n + y) \tag{10}$$

$$E_i(x, y) = r_i(x, y)^p = \left[\frac{I_{conv,i}(x, y)}{I(x, y)}\right]^p \tag{11}$$

$$S_i(x, y) = 255\, I_n^{'}(x, y)^{E_i(x,y)} \tag{12}$$

$$S(x, y) = \sum_i w_i S_i(x, y) \tag{13}$$

where c_i $(i = 0,1,2,...)$ is the different scales, and

w_i is the weight factor for each output

$w_i = 1/n,\ i = 1,2,...n,$

n is the number of scales

◆ Color restoration

– Linear color restoration process for the enhanced color image

- Based on the chromatic information of input image

$$S_j(x, y) = S(x, y)\frac{I_j(x, y)}{I(x, y)}\lambda_j \tag{14}$$

where $j = r, g, b$ represents the R, G, B spectral band, and
S_r, S_g , and S_b are the RGB values of the enhanced color image

- Usage of λ
  - Manual adjustment of the color hue of the enhanced color image
  - Constant, and smaller than but close to 1

Experimental results and discussion

- Result depending on the parameters, $(z,\ c,\ p)$

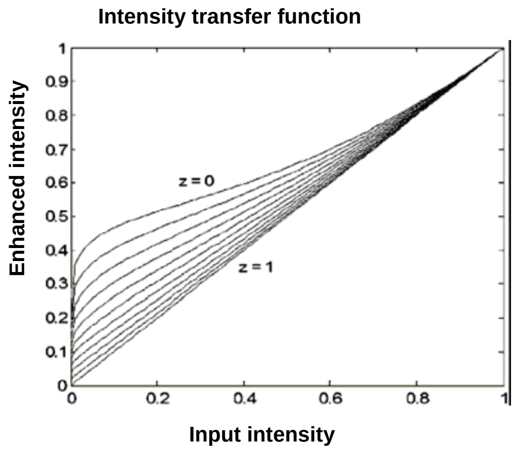
(Ⅰ) $c = 5$ (Ⅱ) $c = 20$ (Ⅲ) $c = 240$

(a) Original

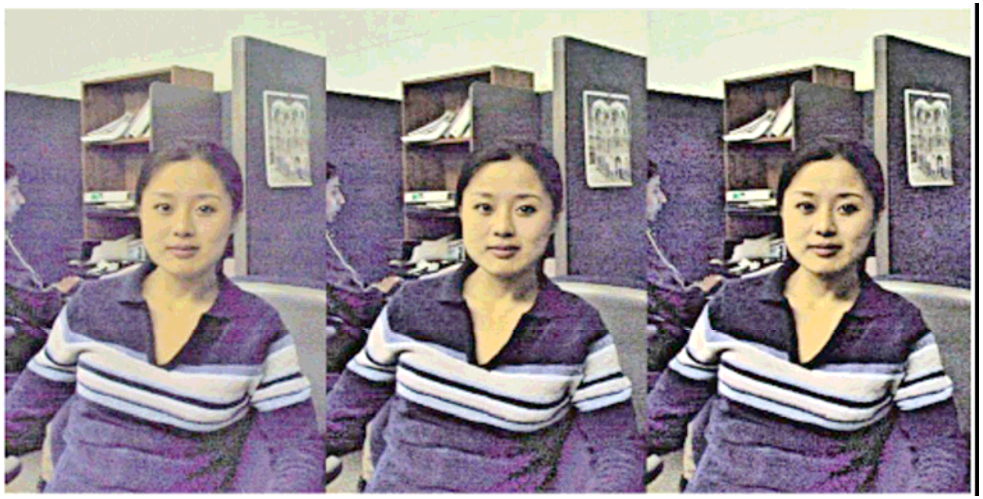
(b) Result images (consideration of local luminance range), $z = 0,\ p = 1$

Fig 5-1. Result images depending on parameter c

(I) $z = 1$ (II) $z = 0.5$ (III) $z = 0$



(d) Result images (consideration of degree of luminance enhancement), $p = 1,\ c = multiscale$



$$S(x, y) = 255\, I_n^{'}(x, y)^{E(x,y)}$$

$$E(x, y) = r(x, y)^p = \left[\frac{I_{conv}(x, y)}{I(x, y)}\right]^p$$

(I) $p = 1$ (II) $p = 2$ (III) $p = 3$

(d) Result images (consideration of degree of contrast enhancement), $z = 0,\ c = multiscale$

Fig 5-2. Result images depending on parameter

◆ Results with comparison of INDANE and AINDANE

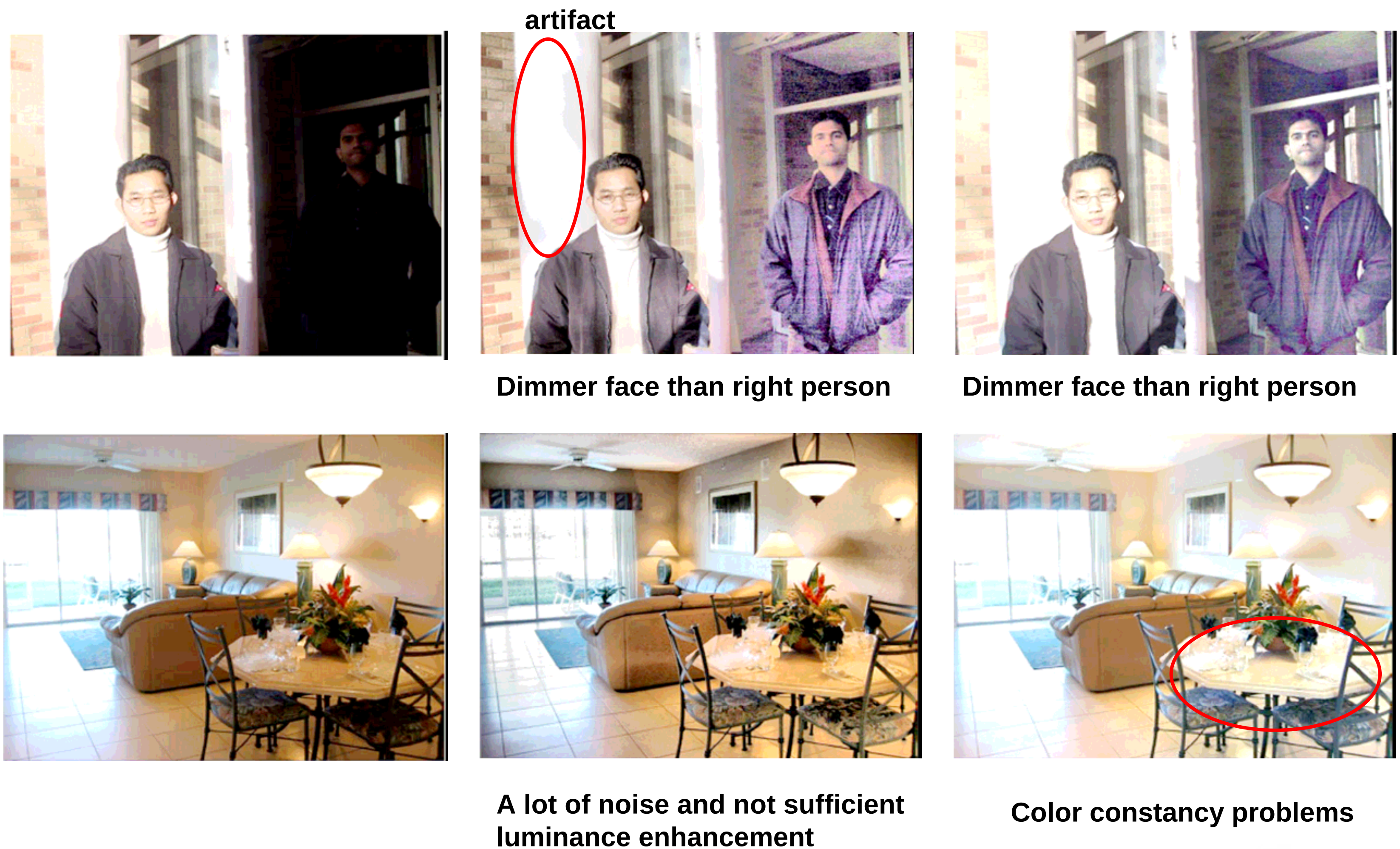
(a) Original (b) INDANE ($z = 0$) (c) AINDANE ($z \neq 0$)

Fig 6. Result images depending on parameter z (luminance control)

(a) Original (b) INDANE ($p = 1$) (c) AINDANE ($p \neq 1$)

Fig 7. Result images depending on parameter p (contrast control)

◆ Results with comparison of other methods



(a) Original (b) AHE (c) retinex

Fig 8-1. Image enhancement comparison

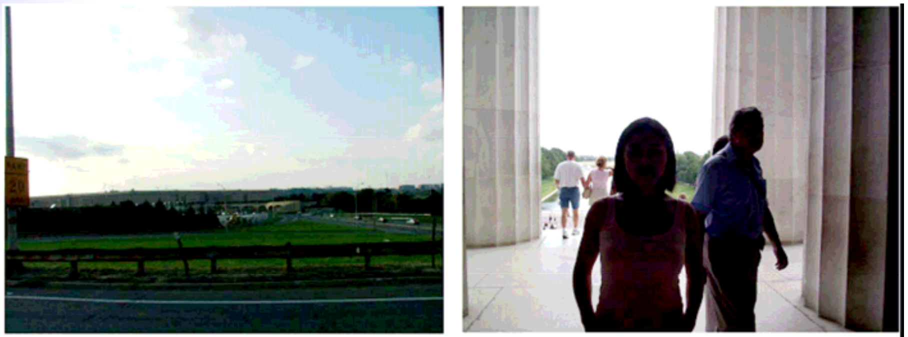
Insufficient luminance enhancement **Higher quality**

Problem in highlighted area **Higher quality**

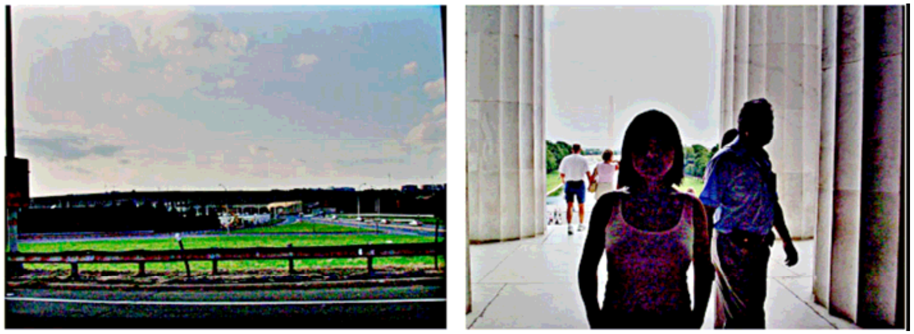
(d) MSRCR (e) INDANE (f) AINDANE

Fig 8-2. Image enhancement comparison.

◆ Results with comparison with other images



(a) Original



Strong contrast enhancement and poor luminance enhancement

(b) MSRCR

Incorrect colors (cloud color) and insufficient luminance enhancement

(c) Retinex

(d) AINDANE

Fig 9. Image enhancement comparison.

◆ Results of AINDANE

(a) (c) (d) (g)

(b) (d) (f) (h)

Fig 10. Image enhancement results obtained by AINDANE

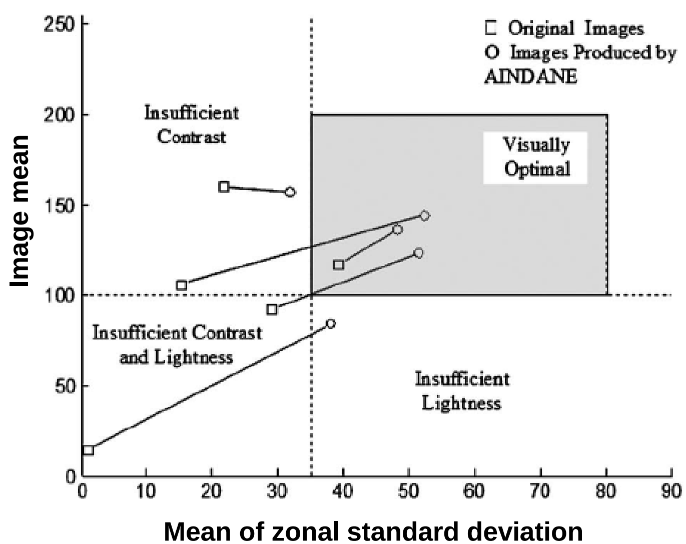
◆ Results of Robust evolution

(a) MSRCR (b) Retinex (c) AINDANE

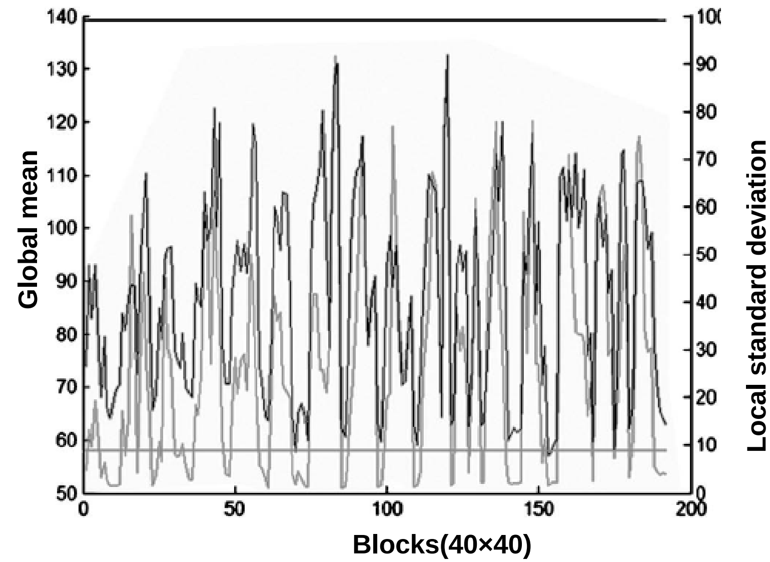
Fig 11. Robust evolution : Left image is the first enhanced image, and right image is the second enhanced image.

◆ Results of statistical method

- Usage of image mean and the mean of zonal standard deviation with blocks
  - Obtainment of overall lightness from image mean
  - Obtainment of overall contrast from the mean of standard deviations



(a)



(b)

Fig 12. Nonlinear transfer function with z

Computational speed

- Computational speed of AINDANE
  - Devices
    - 3.06GHz CPU and 1 Gbyte of memory
  - Coding
    - PhotoFlair version 2.0 for MSRCR and ,C++ for AINDANE
  - 30% processing time from MSRCR
    - Only one channel FFT computation for AINDANCE compared with 3 channel FFT computation for MSRCR

Table 1. Comparison of AINDANE and MSRCR in processing time

Image Size (pixels)	Processing Time by AINDANE (s)	Processing Time by MSRCR (s)
360×240	0.25	1.2
640×480	1.4	4
1024×768	2.8	8
2000×1312	6.7	18

Conclusion

- AINDANE
  - Improvement of visual quality of digital images captured under insufficient or non uniform lighting conditions
  - Two procedure for flexibility and easier control
    - Adaptive luminance enhancement
    - Adaptive contrast enhancement
  - Better performance for visual quality and colors
  - Faster speed compared with MSRCR

◆ Multi-scale Retinex

– Retinex output

$$MR_i(x,y) = \sum_{s=0}^{nn-1} w_s \times (\log I_i(x,y) - \log\{F(x,y) * I_i(x,y)\}) \quad (4)$$

$$F_s(x,y) = K_s e^{-(x^2+y^2)/c_s^2} \quad (5)$$

$$\iint F_s(x,y)\,dxdy = 1 \quad (6)$$

Where nn is the number of scales, and w_s is the weight coefficient associated with output by SSR with the scale c_s.

– Compensation

$$MR_i'(x,y) = MR_i \cdot \left(1 + C \cdot \frac{I_i(x,y)}{\sum I_i(x,y)}\right), \quad C = 125 \quad (7)$$

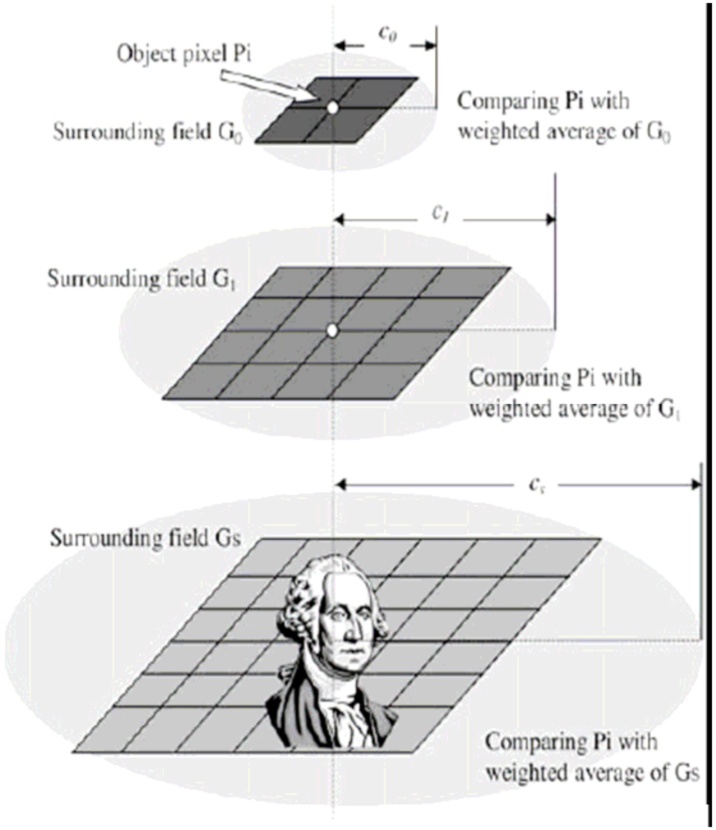


Fig. 3. Diagram expanded in to MSR Technique

- A visibility matching tone reproduction operator for high dynamic range scenes
  - Naive Histogram equalization

$$B_{de} = \log(L_{d\min}) + [\log(L_{d\max}) - \log(L_{d\min})] \cdot P(B_w)$$

Where L_d **is display luminance, and** $B_w = \log L_d$ **is display brightness.**

  - Histogram adjustment with a linear ceiling
    - Limitation of the contrast

$$\frac{dL_d}{dL_w} \le \frac{L_d}{L_w}$$

    - Ceiling of $f(b)$

$$f(b) \le \frac{T\Delta b}{\log(L_{d\max}) - \log(L_{d\min})}$$

Where T **is the total pixel number, and** $\Delta b = (L_{d\max} - L_{d\min})/T$ **is interval of bins.**

    - Tolerance for truncation
      - 2.5% of histogram total