Natural color image enhancement and evaluation algorithm based on human visual system

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Kai-Qi Huang, Qiao Wang, Zhen-Yang Wu

Presented by Ho-Gun Ha

School of Electrical Engineering and Computer Science

Kyungpook National Univ.

Abstract

- Object
  - Color image enhancement
- Proposed method
  - HCCIEE(HVS Controlled Color Image Enhancement and Evaluation algorithm)
    - Multi-scale representation
    - Natural image quality metrics

Introduction

- Two major problems in color image enhancement process
  - More distinguished texture details
  - Perceptually better color of the image
    - Human visual system ➡ Final evaluation of image
- Numerous method for texture detail enhancement
  - Denoising method
  - Contrast based method
    - Histogram equalization
    - Linear contrast stretch
    - Adaptive histogram equalization
    - Contrast-limited adaptive histogram equalization

◆ Color image enhancement method

- Processing each of the three monochrome images
  - R, G, and B channels
  - Enhancing a brightness respectively
- Transform of color spaces
  - LHS ,HIS, YIQ, HSV, etc.
    - Consideration of perceptual color

The HCCIEE algorithm based on HVS Model

- HCCIEE algorithm
  - Two stages structure
    - Enhancement of the texture details
      - Multiscale characteristics
      - Contrast sensitivity functions (CSFs)
    - Rendition of the color image
      - Natural image quality metrics
        - » Color naturalness index (CNI)
        - » Color colorfulness index (CCI)

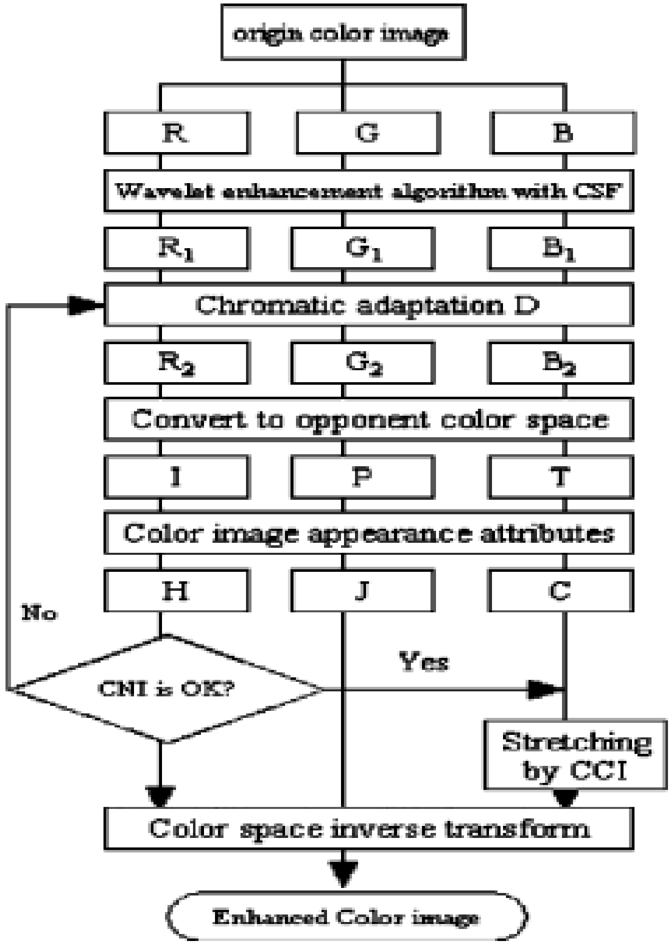

Fig. 1. The flow of HCCIEE algorithm.

- Wavelet-based image enhancement method with contrast sensitivity functions
  - Classical contrast enhancement
    - Histogram specification
    - Adaptive methods
    - Multiscale method
      - Wavelet transform
  - Wavelet - based method
    - Decomposition of image at different scale
    - Modification of wavelet coefficients of image decomposition

◆ General wavelet – based enhancement algorithm

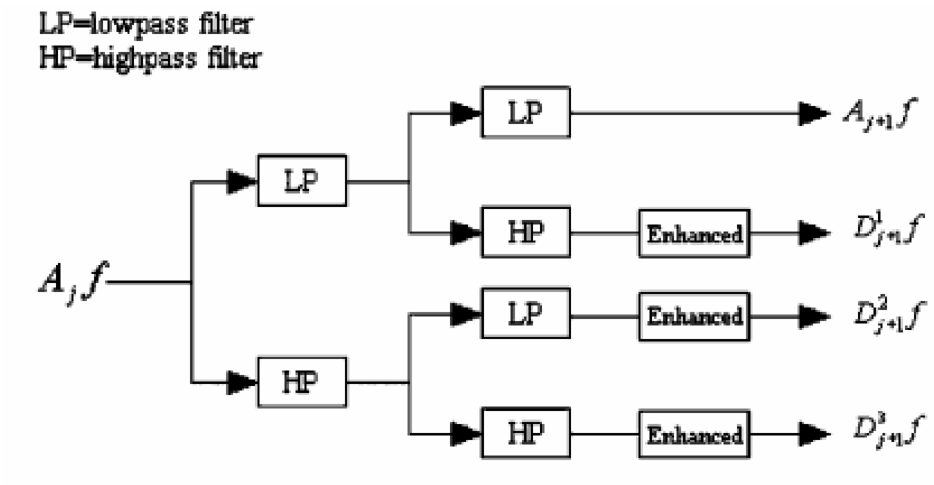

Fig. 2. Multiscale expansion with enhancement for 2 level analysis.

– Characterization of image f

$$A_j f = A_{j+1} f + D^1_{j+1} f + D^2_{j+1} f + D^3_{j+1} f. \quad (1)$$

– Enhanced image f

$$\tilde{A}_j f = \tilde{A}_{j+1} f + \left[F^1_{j+1}\left(D^1_{j+1} f\right) + F^2_{j+1}\left(D^2_{j+1} f\right) + F^3_{j+1}\left(D^3_{j+1} f\right)\right] \quad (2)$$

where $F^i_{j+1}\,(i=1,2,3)$ is called oriented enhancement gain function or mapping function.

– Mapping function

- Implementation of a particular filter sets
  - Easily incorporated into a filter bank
- Use of same mapping function for simplicity
- Occurrence of ringing artifacts or halo artifacts
  - Consideration of HVS in mapping function design

- Threshold model of vision – contrast sensitivity functions in spatial and frequency domain
  - Just Noticeable Difference (JND)
    - Smallest luminance difference that human observer can detect a certain size of object in display
    - Description of threshold model of vision in luminance
  - Some intuition about contrast sensitivity
    - Weber's law
      - Constant of contrast perception at high luminance and/or low spatial frequency
      - Linear relationship : $\Delta L = KL$

- sub - Weber behavior
  - Increment of the contrast perception and the color saturation with luminance
- Increment of the contrast sensitivity with frequency at low spatial frequency

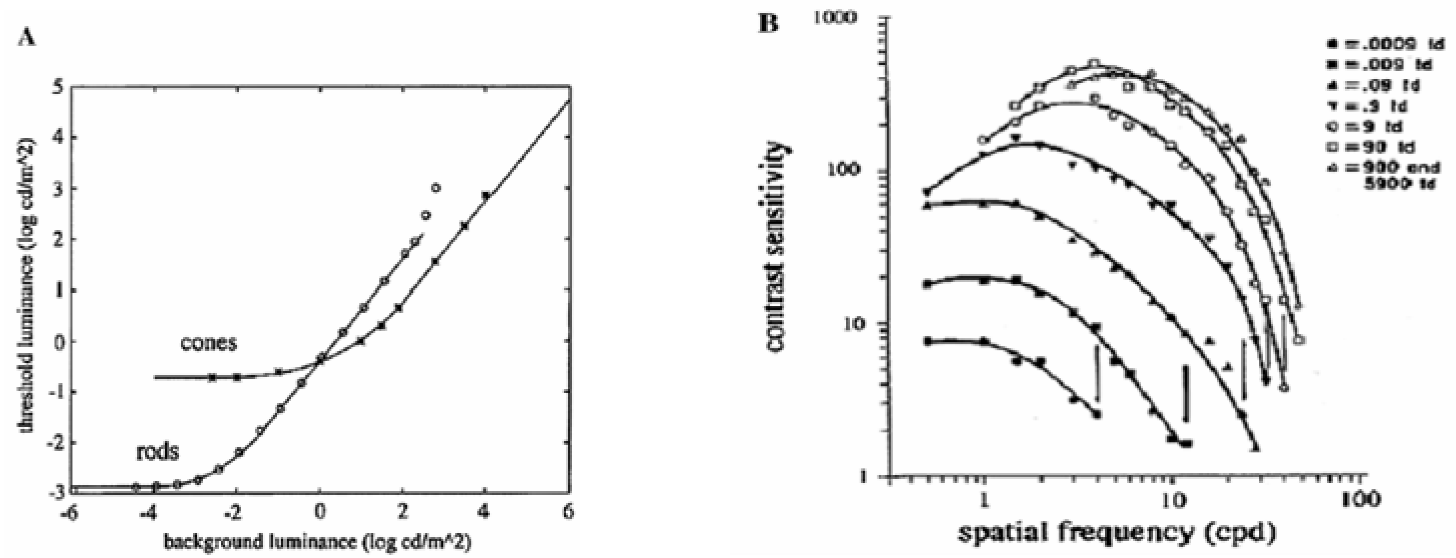

Fig. 3. Threshold models of vision: (A) threshold *vs.* intensity (TVI) function for the rod and cone systems. The curves plot the smallest threshold increment ΔL necessary to see a spot against a uniform background with luminance L (B) Contrast sensitivity functions for sinusoidal gratings illuminated at different mean luminance levels. Levels are specified in Troland (Td) units of retinal luminance (Trolands = luminance in cd/m^2 x pupil area).

– Definition of contrast sensitivity
  - Reciprocal of threshold contrast
    - 1 / threshold contrast

➡ CSF property is characterized to a band pass filter.
HVS's response is modeled by CSF.

- Details enhancement based on wavelet and threshold model of human vision
  - Luminance gain function

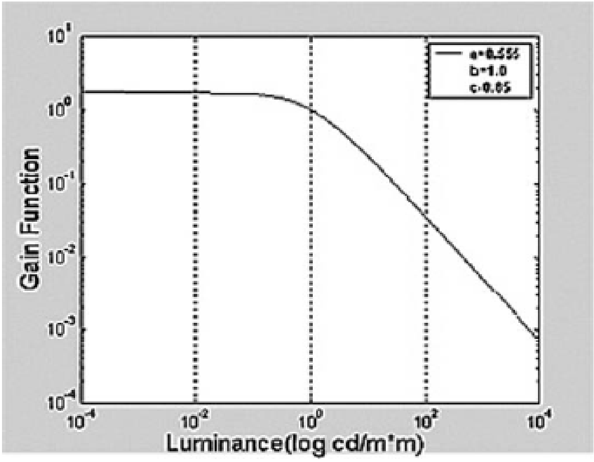

Fig. 4. Luminance gain function (1/TVI), the parameter a=0.555, b=1.0, and c=0.05.

– Gain function

- Choice the cone's TVI-like function

$$G(I) = \frac{1}{a(I+b)^c}. \qquad (3)$$

where I represents the cone signal that is used to set the level of adaptation.

a, b, and c are constant.

– Details enhancement function in the wavelet inverse transform

$$\tilde{F}_j(D_j f) = G\left(A_{j+1} + \tilde{F}_{j+1}\left(\sum_{i=1}^{3} D_{j+1}^{i} f \right)\right). \qquad (4)$$

– Initial function

$$\tilde{F}_J = G(A_J f). \qquad (5)$$

where i is the wavelet orientation,

$A_J f$ is the low-pass residual,

and the gain function is the same in different orientation to reduce computation.

- ◆ Color rendition according to natural image quality metrics
  - – Need of suitable color re-rendition operation
    - Unnatural or unvivid of only detail enhanced image
- ◆ Color image quality metrics
  - – Producing best looking image rather than achieving luminance and color fidelity
    - Naturalness
      - – Degree of correspondence between human perception and reality world
    - Colorfulness
      - – Degree of color vividness

– Computing of the CNI

[step1:] Transforming color image in RGB space to other color space such as CIELUV color space.

[step2:] Computing the luminance (L), hue (H), and saturation (S), respectively.

[step3:] Thresholding L and S components: L values between 20 and 80 are kept, S values over 0.1 are kept.

[step4:] Defining three kinds of pixels according to hue value: 25-70 is called "skin" pixels, 95-135 is called "grass" pixels, and 185-260 is called "sky" pixels.

[step5:] Calculating averaged saturation values for "skin" $S_{average\_skin}$ "grass" $S_{average\_grass}$ and "sky" $S_{average\_sky}$ pixels and numbers of "skin" pixels n_{skin} "grass" pixels n_{grass} and "sky" pixels n_{sky}.

[step6:] Calculating local CNI values for “skin”, “grass”, and “sky” pixels:

$$N_{skin} = \exp(-0.5 * ((S_{average\_skin} - 0.76) / 0.52)^2)^4 \quad (6)$$

$$N_{grass} = \exp(-0.5 * ((S_{average\_grass} - 0.81) / 0.53)^2) \quad (7)$$

$$N_{sky} = \exp(-0.5 * ((S_{average\_sky} - 0.43) / 0.22)^2) \quad (8)$$

[step7:] Calculating the global CNI values:

$$N_{image} = (n_{skin} * N_{skin} + n_{grass} * N_{grass} + n_{sky} * N_{sky}) / (n_{skin} + n_{grass} + n_{sky}) \quad (9)$$

where N_{image} varies from 0 to 1.

0: the most unnatural image.
1: the most natural image.

– Definition of colorfulness index

$$C_k = S_k + \sigma_k. \quad (10)$$

where S_k is the average saturation of image k,
σ_k is standard deviation,
and C_k varies from 0 to $C_{\max}$.

0 : achromatic image.
$C_{\max}$: the most colorful image.

– New colorfulness metrics

- sRGB color space
- Efficient computing of colorfulness

$$C_k = \sigma_{rgyb} + 0.3 \cdot \mu_{rgyb}. \quad (11)$$

$$\sigma_{rgyb} = \sqrt{\sigma^2{}_{rg} + \sigma^2{}_{yb}}. \quad (12)$$

$$\mu_{rgyb} = \sqrt{\mu^2{}_{rg} + \mu^2{}_{yb}}. \quad (13)$$

where rg and yb are the components in sRGB color space.

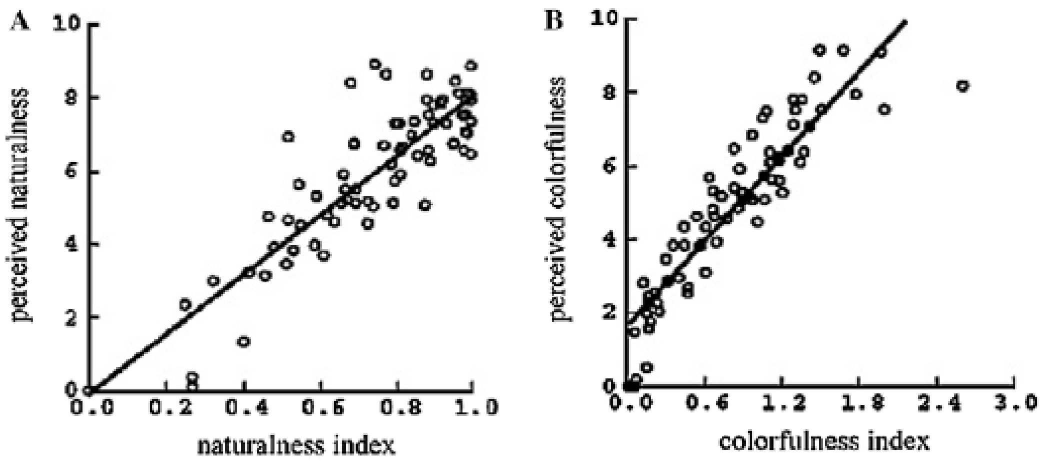

Fig. 5. (A) Naturalness judgments *vs.* the naturalness index. (B) Colorfulness judgments *vs.* the colorfulness index.

- Correlation of data
  - CNI – 0.87
  - CCI – 0.91
- Best range of CNI and CCI for human perception
  - CNI – close to 1
  - CCI – about 16 ~ 20

◆ Color rendition

– Evaluation of natural color image metrics

- Use of CNI and CCI

– Simple chromatic adaptation model

$$R_2 = \left[\left(L_1 \frac{D}{R_1}\right) + (1 - D)\right] R_1 . \qquad (14)$$

$$G_2 = \left[\left(L_1 \frac{D}{G_1}\right) + (1 - D)\right] G_1 . \qquad (15)$$

$$B_2 = \left[\left(L_1 \frac{D}{B_1}\right) + (1 - D)\right] B_1 . \qquad (16)$$

where L_1 is luminance which can be computed as a weighed sum of pixels in the $R_1G_1B_1$ component of the color image.

D is a degree-of-adaptation factor.

– Conversion to a opponent-color space (IPT)
  - Construction of a uniform perceptual color space
    - – Good prediction of constant perceived hue
  - Acquisition of Simplicity, Accuracy, Applicability in image processing

– Conversion to a simple coordinate (HJC)
  - Hue angle (H), Lightness (J), chroma (C)
  - Transform equation

$$J = I \tag{17}$$

$$C = \sqrt{P^2 + T^2} \tag{18}$$

$$H = \tan^{-1}\left(\frac{P}{T}\right) \tag{19}$$

  - Stretching a chorma

$$C_1 = C^{\beta} \tag{20}$$

where β can be chosen by another color metrics CCI.

Experimental Results

- Comparing HCCIEE with other color image enhancement method

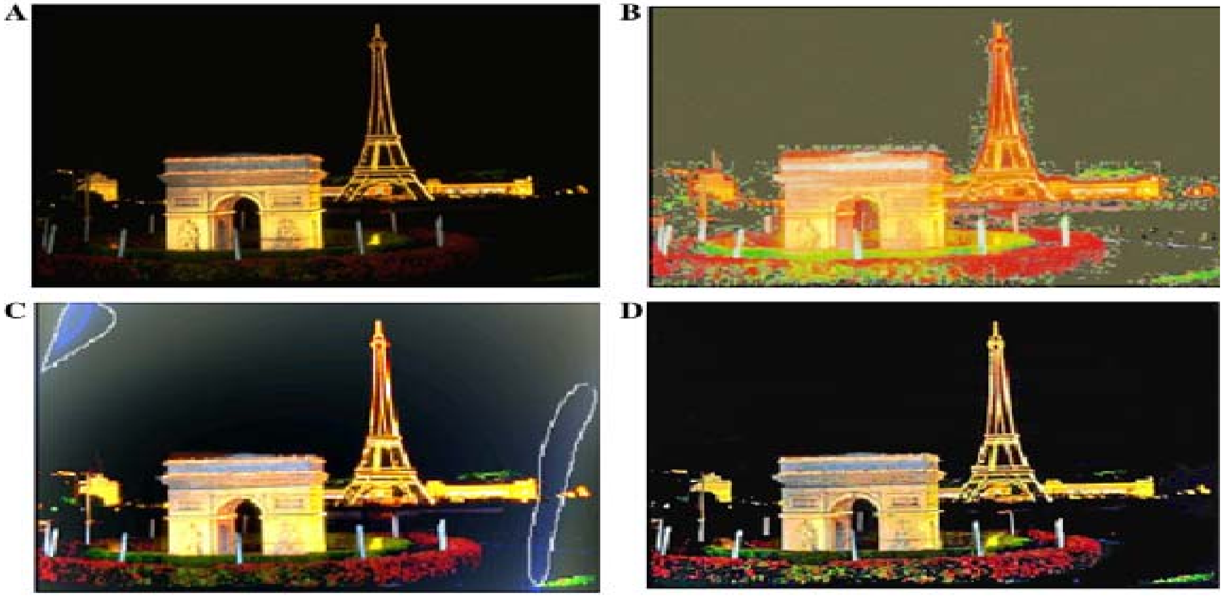

Fig. 6. (A) is the original imgae “Paris in night”.(B) The enhanced result by the HE only in luminance components. (C) The enhanced result by multiscale Retinex color restoration (MSRCR) algorithm, halo artifacts marked with white lines. Gain factor is [250,80,15]. (D) The result of HCCIEE algorithm.

– Texture details

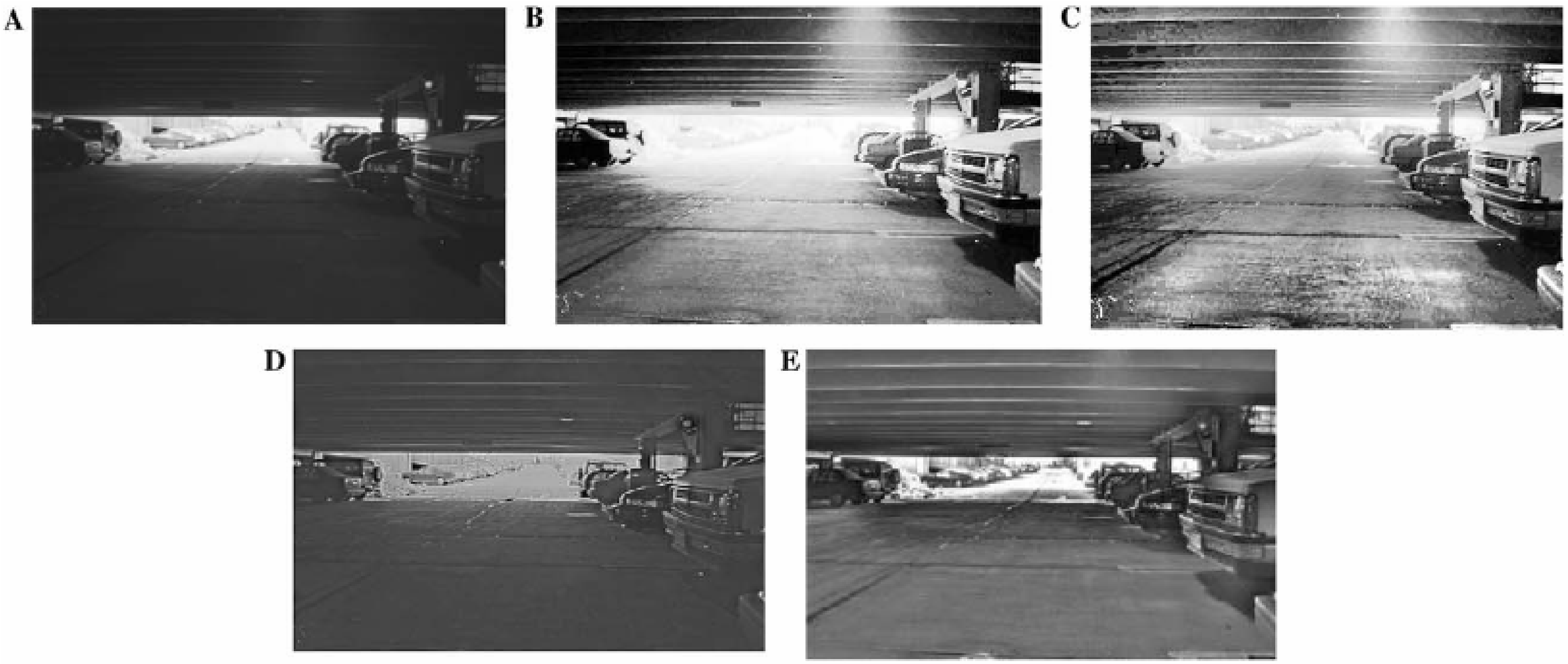

Fig. 7. Example result of several image enhancement algorithm: (A) original image, (B) histogram equalization result, (C) CLAHE result, (D) wavelet method, and (E) result of the first stage processing of our HCCIEE algorithm.

– Color rendition

- Naturalness
- Colorfulness

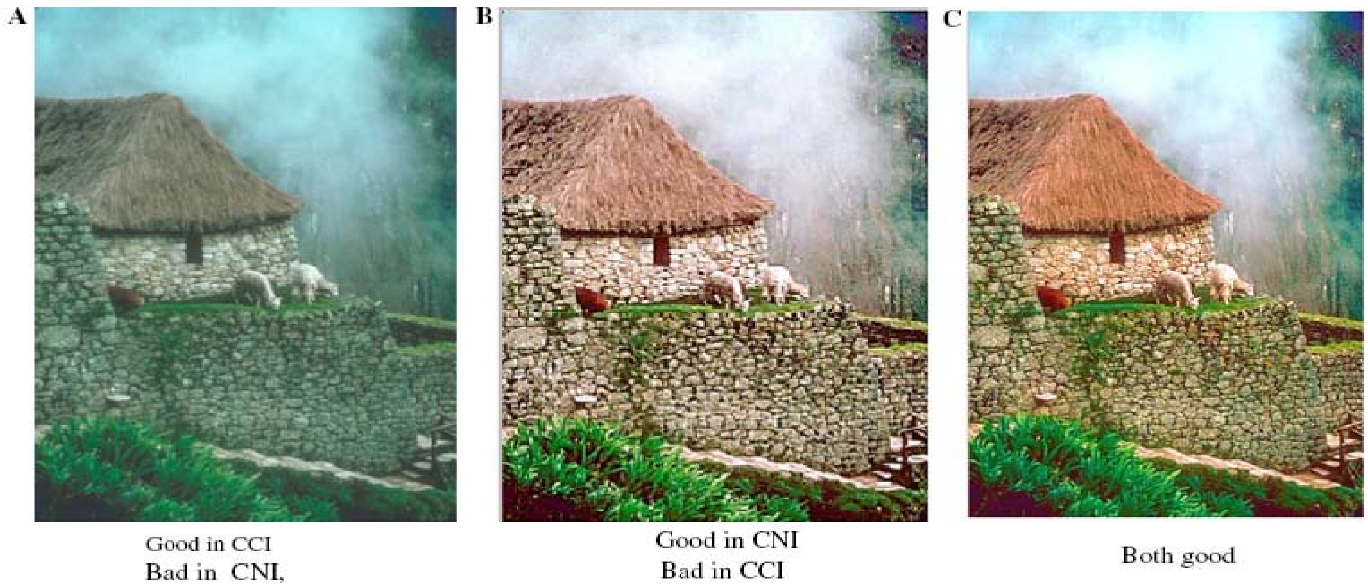

Fig.8. (A) Origin image “hut and sheep”. (B) naturalness processed image, and (C) HCCIEE algorithm.

– Color - shifting image

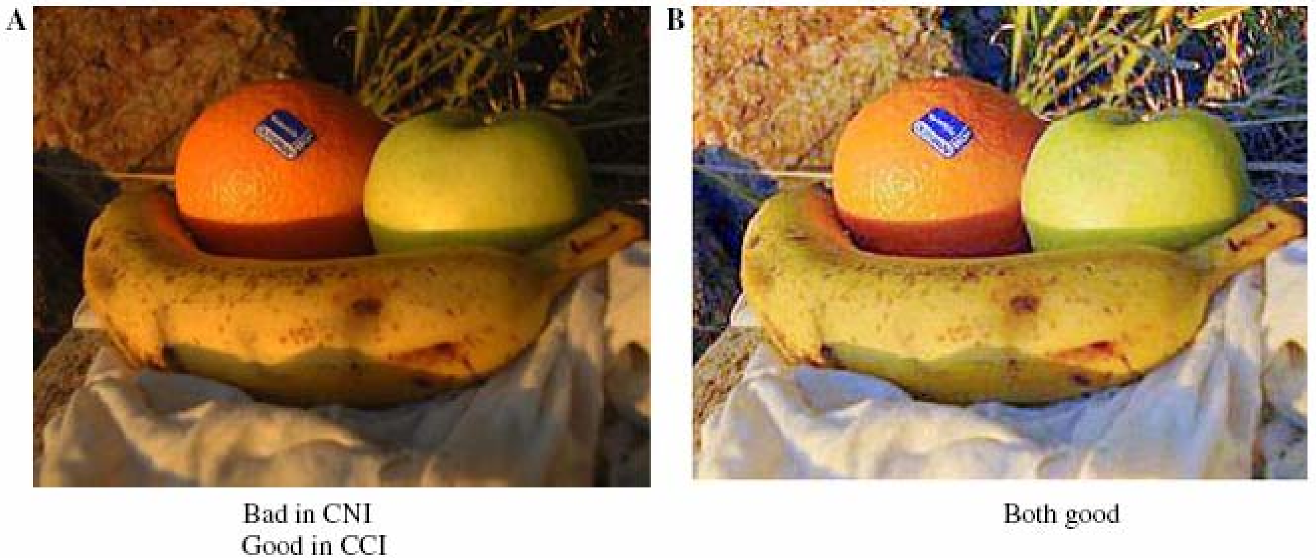

Fig.9. (A) Origin image. (B) naturalness processed image.

Table 1. Measure naturalness and colorfulness.

Images\metrics	Fig. 8. "hut and sheep" [47]			Fig. 9. " fruit under sun" [42]	
	Origin (A)	Naturalness processed (B)	HCCIEE algorithm (C)	Origin (A)	Naturalness processed (B)
Color naturalness index (CNI: 1 is best)	0.6712 (bad)	0.9534 (good)	0.9578 (good)	0.5126 (bad)	0.9726 (good)
Color colorfulness index (CCI: 16–20 is good)	16.6033 (good)	9.3497 (bad)	15.9675 (good)	16.7568 (good)	19.5132 (good)

– Original real scene image taken by digital camera

Fig.10. (A) Origin image captured by canon digital in auto-model sets CNI=0.7238 and CCI=15.1172. (B) HCCIEE algorithm enhanced color image CNI=0.9418 and CCI=19.2317.

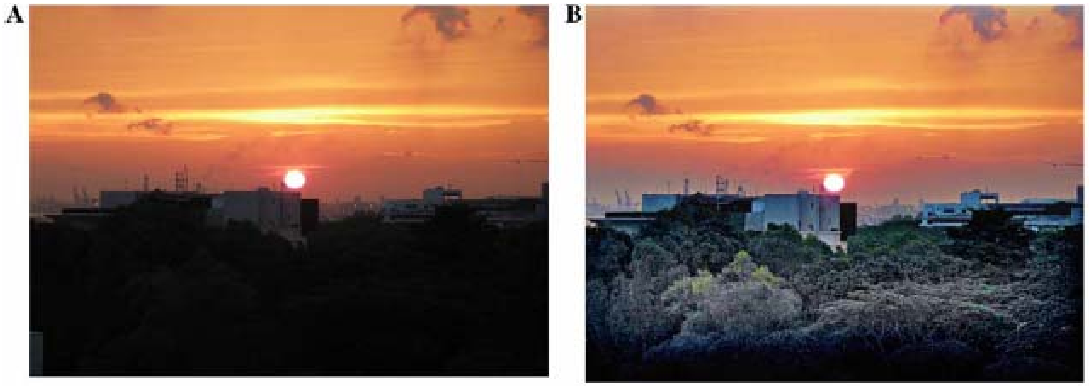

Fig.11. (A) Origin image captured by canon digital in auto-model sets CNI=0.7781 and CCI=21.2713. (B) HCCIEE algorithm enhanced color image CNI=0.9732 and CCI=19.6171.

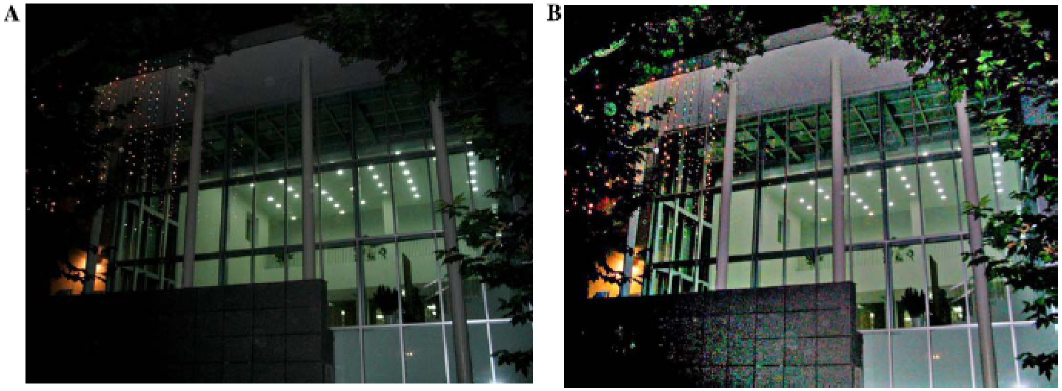

Fig.12. (A) Origin image captured by canon digital in auto-model sets CNI=0.4813 and CCI=13.7321. (B) HCCIEE algorithm enhanced color image CNI=0.9398 and CCI=19.4715.

– Statistical results of CNI,CCI

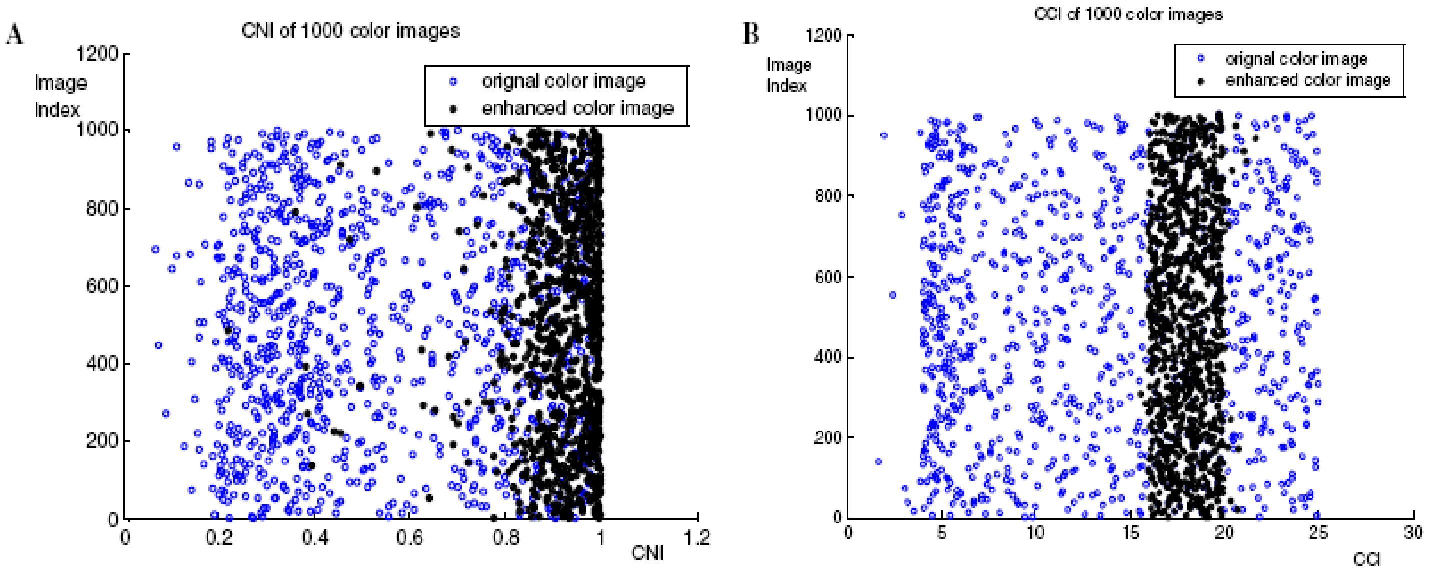

Fig.13. Statistical results of (A) CNI and (B) CCI of 1000 test images including all testing figures in the paper. The horizontal axes are the CNI/CCI value and vertical axes are the image number index.

Conclusion

- Proposed novel algorithm
    - Wavelet - based detail enhancement
    - Better color rendition
  - Application
    - Visual surveillance
      - Luminance and details preprocessing
    - Photo retrieval
      - Details and color reproduction
- Future work
  - Establishing relation between CNI and CCI
    - Mathematical representation
  - Trade off algorithm between speed and effectiveness