Color image enhancement based on the discrete cosine transform coefficient histogram

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Abstract

- Histogram shifting with alpha rooting
  - Purpose
    - Contrast enhancement for color image
      - Based on discrete cosine transform coefficients
  - Method
    - Adapting spatial domain technique into transform domain
      - Low complexity of computations
      - Ease of manipulation of frequency composition of image
      - Preservation of phase information
  - Combination of alpha rooting
    - Effectiveness for enhancing overexposed image

Introduction

- Spatial domain method
  - Histogram equalization
    - Advantage
      - Inherent dynamic range expansion
    - Disadvantage
      - Case of image with data clustered around certain intensity values
        - » Appearance of artifact of image
        - » Appearance overall tonal change of image

❑ Transform domain method

- Process
  - Transforming image intensity data into specific domain
    - Altering high-frequency content of image
      - » Using discrete cosine, fourier, and wavelet transforms
- Advantage
  - Low complexity of computations
  - Ease of manipulating frequency composition of image
- Disadvantage
  - Appearing block artifacts
  - Not enhancing all parts of image simultaneously
  - Difficult to automate image enhancement procedure

❑ Proposed method

- Concept
  - Implementing histogram reshape
    - Based on spatial domain enhancement in transform domain
- Process
  - Altering logarithmic DCT coefficient histogram
    - Shifting specific bins in histogram
  - Combination of alpha rooting
    - Enhancement of image from overexposure

Background

- Color space PCA
  - Purpose
    - Decoupling chromatic information from achromatic information
      - Division input RGB image into luminance and chromatic components
  - Procedure
    - Step 1
      - Construction of matrix $\boldsymbol{I}$ from RGB image
      - Converting R, G, and B components into single slices

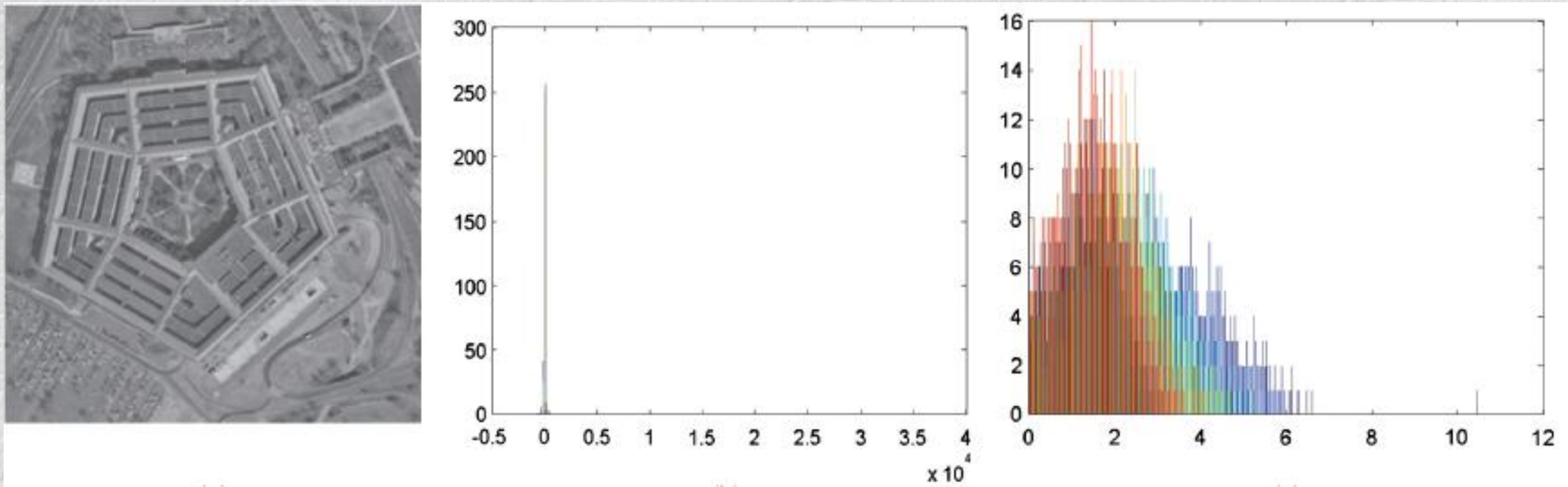
$$I = \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

- Step 2
  - Obtaining matrix ***F***
    - » Subtracting mean value from matrix ***I***

$$F = I - \text{mean}(I) \tag{2}$$

- Step 3
  - Calculation of three eigenvalues λ_1, λ_2, and λ_3
  - Calculation of eigenvectors of matrix ***FF'***
- Step 4
  - Obtaining three components (one luminance and two chromatic information)
    - » Projecting matrix ***F*** to new set of eigenvectors

- Logarithmic DCT coefficient histogram
  - Representing distribution of frequency content of image
  - Utilizing all histogram shaping-based spatial domain technique into transform domain



(a) (b) (c)

Fig. 1. The function of logarithmic transform: (a) is the test image pentagon; (b) is the 256 level DCT coefficient histogram; (c) is the 256 level logarithmic DCT coefficient histogram.

– Logarithmic transform

- Preserving phase of transform image
  - Representation of phase matrix p(u,v) using DCT coefficients d(u,v)

$$p(u,v) = angle\left[d(u,v)\right] \tag{3}$$

- Taking logarithm of coefficients d'(u,v)

$$d'(u,v) = \ln\left[d(u,v) + \lambda\right] \tag{4}$$

where λ is the shifting coefficient, usually set to 1.

- Return coefficients to standard transform domain

$$d(u,v) = e^{d'(u,v)} \cdot e^{jp'(u,v)} \tag{5}$$

- Objective judge of enhancement performance
  - Use of image entropy measurement
    - Representing formula of entropy

$$H = -\sum p(x_i) \log p(x_i) \tag{6}$$

where $p(x_i)$ is the possibility of the intensity value x_i. By default, entropy uses $n = 256$ gray levels for grayscale image.

- Comparison of histogram equalization in spatial and transform domain

(a) (b) (c)

Fig. 2. The comparison of histogram equalization in both the spatial domain and transform domains. The transform domain histogram has both better objective and subjective performance, and it preserves the most significant phase information of the image: (a) is the original image and the entropy equals to 6.5751; (b) is the reconstructed image only by the phase information of the original image; (c) is the resulting image of histogram equalization in spatial domain and the entropy equals to 5.8540.

Methodology

- General framework of proposed method

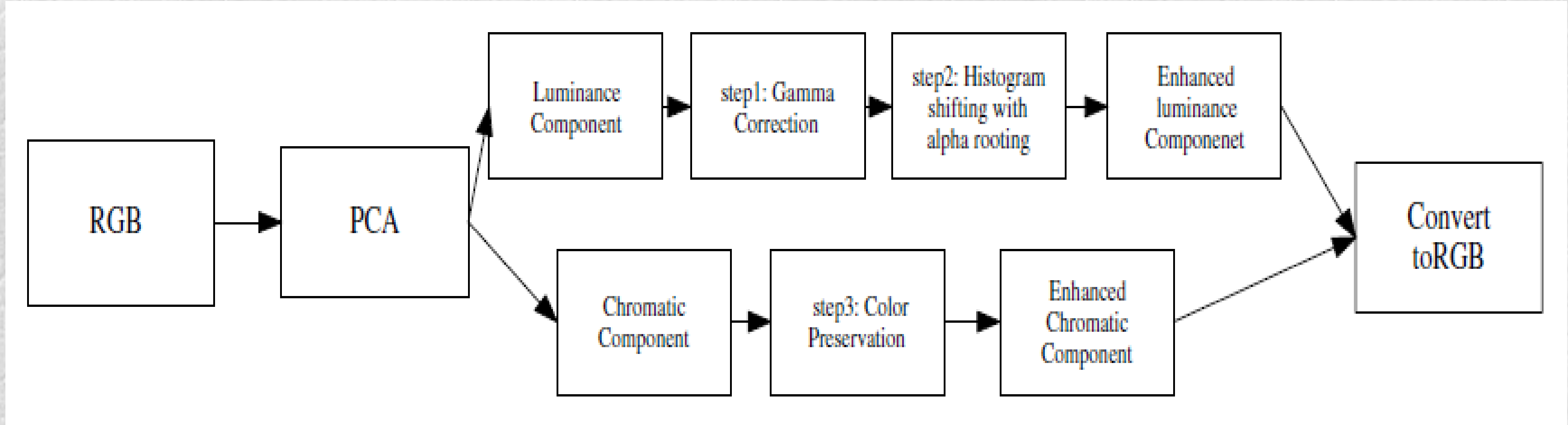


Fig. 3. The process flow of the histogram shifting color image-enhancement algorithm. It is implemented in three steps: (1) gamma correction is used to adjust the dynamic range; (2) histogram shifting with alpha rooting is used to enhance the contrast; (3) color preservation is used to adjust the saturation.

– Procedure

- Step 1
  - Applying gamma correction on luminance component
    - » Global adjustment of background brightness
- Step 2
  - Application of histogram shifting method
    - » Enhancement of contrast
- Step 3
  - Weighting chrominance components by constant factor
    - » Compensation for loss of saturation

– Dynamic range compression

- Purpose
  - Mapping natural dynamic of signal to smaller range
- Method
  - Application of gamma correction operation with parameter γ
    - » Adjusting illumination of image

$$x' = W\left(\frac{x}{W}\right)^{1/\gamma} \quad (6)$$

where x is original gray image and W is the white value (equal to 255 in 8 bit images).

- Resulting image

(a) (b)

Fig. 4. The results of gamma correction: (a) is the original image; (b) is the enhanced image obtained by gamma correction.

❑ Histogram shifting

- Concept
  - Taking histogram of logarithmic DCT coefficients
  - Applying shift in positive direction
    - Relatively larger shift for larger coefficients
- Process
  - Shifting operation in logarithmic DCT domain
    - Equalization of scaling DCT coefficient

$$d(u,v) = \mathrm{dct2}\left[x(i,j)\right] \tag{8}$$

$$l(u,v) = \log\left[\left|d(u,v)\right| + 1\right] \tag{9}$$

- Shifting histogram of logarithmic DCT coefficient
  - Equalization of adding constant in logarithmic domain

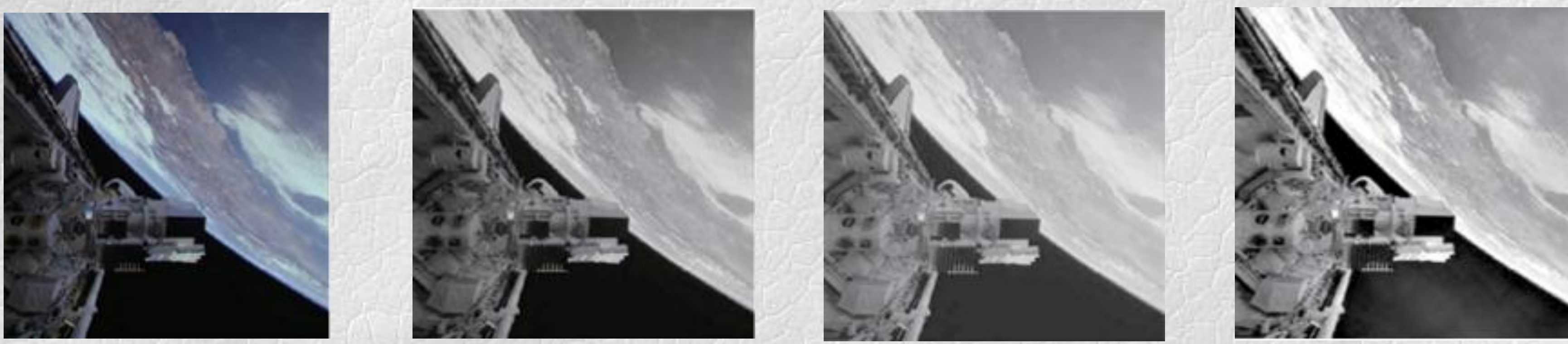
$$l'(u,v) = l(u,v) + c \quad (10)$$

$$d(u,v) = e^{l(u,v)} \quad (11)$$

$$d'(u,v) = e^{l'(u,v)} = e^{l(u,v)+c} = e^{c} d(u,v) \quad (12)$$

where $x(i,j)$ is the original image coefficient, $d(u,v)$ is the DCT coefficient, $l(u,v)$ is the logarithmic DCT coefficient, $l'(u,v)$ is the logarithmic DCT coefficient after shifting operation. $d'(u,v)$ is the enhanced DCT coefficient.

- Resulting image
  - Applying gamma correction
    - Increasing brightness
  - Applying histogram shifting
    - Improving contrast
    - Sharpening edge



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

Fig. 5. The results of gamma correction and histogram shifting: (a) is the original shuttle image; (b) is the luminance component of the original image; (c) is the resulting image after applying gamma correction to (b); (d) is the resulting image after applying histogram shifting to the image in (c).

– Specific details of proposed method

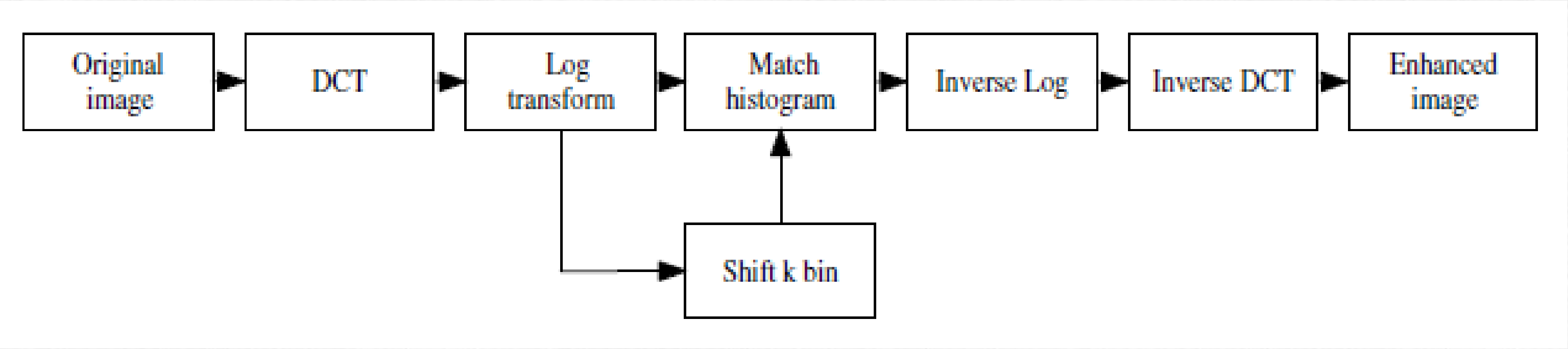


Fig. 6. Diagram of the histogram shifting method.

– Resulting image

- Choosing optimal shifting distance for parameter k
  - Based on entropy

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

Fig. 7. Choosing the optimal shifting distance for parameter k based on entropy: (a) is the original image and the entropy is 6.5751; (b) is the enhanced image by shifting three bins and the entropy is 7.2302; (c) is the enhanced image by shifting seven bins and the entropy is 7.7456; (d) is the enhanced image by shifting 10 bins and the entropy is 6.5625; (e) shows the profiles of the original logarithmic DCT histogram

and the shifted logarithmic DCT histogram; (f) is the curve of shifting distance k versus the entropy value.

– Modification of histogram shifting method
  - Concept
    - Combining histogram shifting with alpha rooting
      - » Inserting new parameter in logarithmic transform

$$l(u,v) = \log\left[\left|d(u,v)\right|^{a} + 1\right] \qquad (13)$$

- Feature
  - Retaining texture information

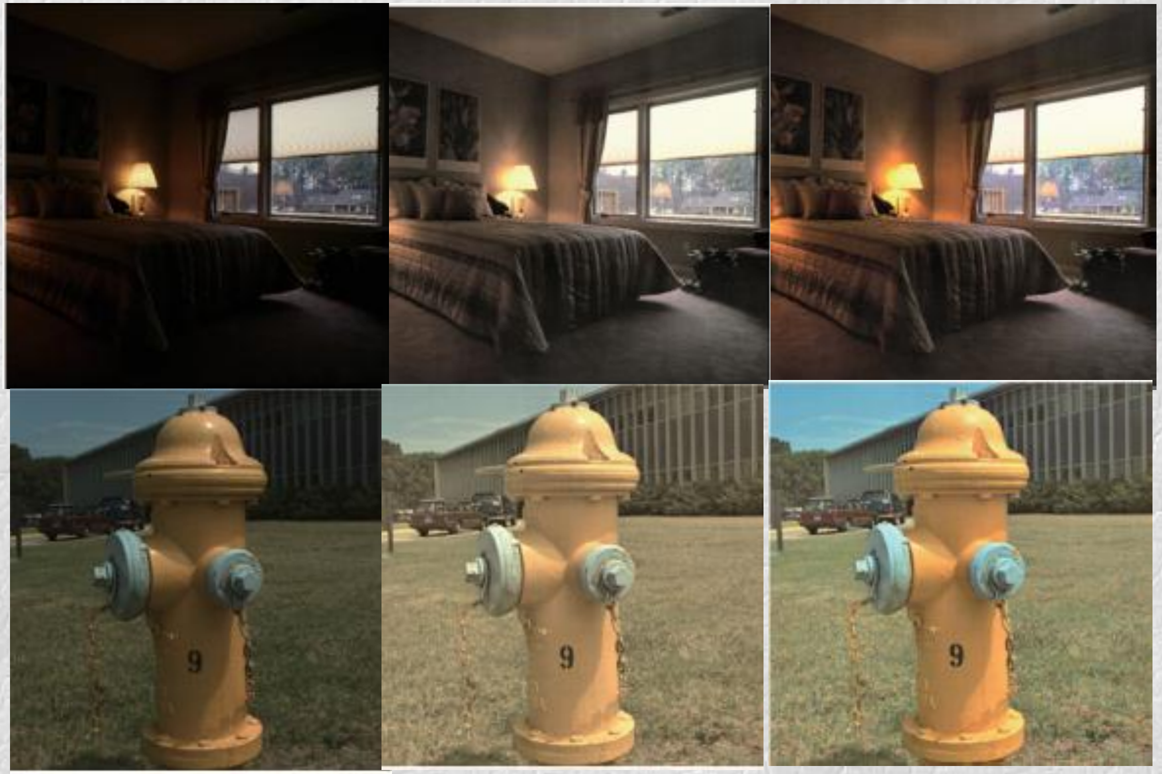
(a) (b) (c) (d)

Fig. 8. The benefits of combining alpha rooting and histogram shifting together. (a) is the original image and the entropy is 7.2829; (b) is enhanced by combing alpha rooting and histogram shifting together. The shifting distance is three bins and the alpha is 0.9. The entropy of (b) is 7.6920; (c) is enhanced by alpha rooting only and the alpha equals to 0.9. The entropy of (c) is 7.3215; (d) is the enhanced image by histogram shifting only. The shifting distance is three bins and the entropy is 6.0237.

- Color preservation
  - Concept
    - Compensation for chromatic components
      - According to changing luminance component
  - process
    - Multiply constant factors (color preservation factors)

$$C_1^{'} = a_1 C_1 \tag{14}$$

$$C_2^{'} = a_2 C_2 \tag{15}$$



(a) (b) (c)

Fig. 9. Enhanced image by processing only the illumination component and both illumination and chrominance components on images: girl, building, bed, and hydrant: (a) are the original images; (b) are the enhanced image without color preservation processing; (c) are the enhanced images with color preservation processing.

Table 1. The values of the color preservation factors α1 and α2.

Image	α_1	α_2
Girl	1.7	1.7
Building	2.0	3.5
Bed	2.0	2.0
Hydrant	2.1	2.0

Computer simulations

- Comparisons with other existing algorithms

Fig. 10. Examples of enhanced results of all the algorithms.

Table 2. Performance comparison table of different techniques.

	HSAR	MCE	MCEDR	CES	MSRCR
Average score	4.1	2.5	3	3.5	3.9

Table 3. Performance comparison table of different techniques.

Techniques	Operation per pixel
HS	1M
HSAR	$2E + 1M$
MCE	2.19M
MCEDRC	$0.03E + 3.97M$
CES	$0.05E + 4M$
MSRCR	$18E + 1866378M$

Conclusion

- New technique for color enhancement
  - Concept
    - Based on manipulation of logarithmic DCT coefficients
  - Method
    - Combination histogram shifting with alpha rooting
      - Enhancing overexposed image