An Integrated Neighborhood Dependent Approach for Nonlinear Enhancement of Color Images

Li Tao and Vijayan Asari
VLSI Systems Laboratory
Department of Electrical and Computer Engineering
Old Dominion University, Norfolk, VA 23529

Abstract

In this paper, we propose a new image enhancement algorithm INDANE (Integrated Neighborhood Dependent Approach for Nonlinear Enhancement of Color Images), which is applied to improve the visibility of the dark regions in digital images. INDANE is a combination of two independent processes: luminance enhancement and contrast enhancement. The luminance enhancement, also regarded as a process of dynamic range compression, is essentially an intensity transformation based on a specifically designed nonlinear transfer function. The contrast enhancement transforms the pixel’s intensity based on the relationship between the center pixel and its surrounding pixels. For color images, they are firstly converted to intensity (grayscale) images, and then are treated by the proposed image enhancement process.

Keywords: image enhancement, luminance space, dynamic range compression, pixel based modeling, contrast enhancement, neighborhood dependent adjustment

1. Introduction

The basic mechanism of image enhancement for improving the visibility of the dark regions in digital images is the dynamic range compression of all the spectral bands or just the luminance of the original image. The processing of the image’s luminance instead of every spectral band may be preferred for faster processing, more predictable and controllable results of the color rendition.

After luminance enhancement, the image’s contrast will definitely be degraded with output pictures looking gray-out. In order to improve the overall quality of the images, contrast enhancement process must be applied to restore or even enhance the contrast information from the original image. However, conventional contrast enhancement techniques are not sufficient for that purpose and they may lead to dynamic range expansion.

The proposed algorithm has two separate processes. Luminance enhancement is first applied to the image through a pixel intensity transformation that is implemented by using a nonlinear transfer function. This transfer function can be manually or automatically adjusted to achieve appropriate luminance enhancement. After luminance enhancement, the image is then treated by the contrast enhancement which, unlike the conventional techniques, is an adaptive process based on the intensity information of both the processed (center) pixel and its surrounding neighbors. The luminance information of surrounding pixels is obtained by using 2D discrete spatial convolution with a Gaussian kernel. Therefore, pixels with the same luminance may have different outputs depending on their neighborhood pixels. In this way, picture contrast and fine details can be optimally enhanced while dynamic range expansion can be controlled without degrading image quality.

The separation of the luminance enhancement and the contrast enhancement is fundamentally different from multi-scale retinex (MSR) in which both processes are realized simultaneously, and it also makes it possible to finely tune both processes to achieve optimal results. Unlike the standard MSR, only luminance information is processed to obtain predictable and consistent color rendition for color images.

2. Algorithm

First, color images in RGB color space are converted to intensity (grayscale) images $I(x, y)$ and normalized. The normalized intensity $I_n(x, y)$ is transformed by applying the transfer function defined below

$$I_n' = \frac{(I_n^{0.24} + (1 - I_n) \cdot 0.5 + I_n^2)}{2}$$  \hspace{1cm} (1)

This transformation can largely increase the luminance for those dark pixels (regions) while brighter pixels (regions) have lower or even negative enhancement. The constants in Eq.(1) can be adjusted based on the overall intensity level of the input image so that the luminance enhancement can be finely tuned to achieve optimal results.
Next, 2D discrete convolution is carried out on the original intensity image \( I(x, y) \) by using Gaussian function \( G(x, y) \) as the convolution kernel, which has a form like

\[
G(x, y) = K \cdot e^{-\frac{(x^2+y^2)}{2C^2}}
\]

(2)

where \( K \) is determined by

\[
\int \int K \cdot e^{-\frac{(x^2+y^2)}{2C^2}} \, dx \, dy = 1
\]

(3)

and \( C \) is the scale or Gaussian surround space constant. The convolution can be expressed as

\[
I'(x, y) = I(x, y) \ast G(x, y)
\]

(4)

The convolution result \( I'(x, y) \) contains the luminance information of neighboring pixels. It is compared with the center pixel for contrast enhancement process, which is described in the expression below

\[
R(x, y) = 255 \cdot I'(x, y)^r(x, y)
\]

(5)

where the exponent \( r(x, y) = I'(x, y) / I(x, y) \). In this way, the contrast can be enhanced for the images produced by luminance enhancement. The center pixel’s luminance can be increased or decreased depending on if \( r(x, y) \) is larger or smaller than 1 (surrounded by brighter pixels or darker pixels).

For optimal results of image enhancement, contrast enhancement is performed with multiple convolution results from different scales. The final output is a linear combination of the contrast enhancement results based on multiple scales, which can be expressed like

\[
R(x, y) = \sum_i w_i R_i(x, y)
\]

(6)

where \( i = 1, 2, 3, \ldots \) represents different scales and \( w_i \) is the weight factor for each contrast enhancement output \( R_i(x, y) \). The choice of scales is related to the quality of the enhanced images. The scales used in this work are 5, 20 and 240, and \( w_i = 1/3 \).

The enhanced color images can be obtained based on the enhanced intensity images through a linear color restoration process described by the following equation

\[
R_j(x, y) = R(x, y) \frac{I_j(x, y)}{I(x, y)} \lambda
\]

(7)

where \( j = r, g, b \) represent the R, G and B spectral band respectively, and \( R_r, R_g \) and \( R_b \) are the enhanced RGB values of the enhanced color image. \( \lambda \) is introduced to adjust the color hue of the three spectral bands. The output color images can be further refined with a color saturation and white balance adjustment.

3. Experimental Results

The proposed image enhancement algorithm has been applied to process digital images taken by digital still-image cameras under various illuminating conditions. The output images generally have a good quality, with fine details, well-balanced contrast and luminance across the whole image, and a natural color rendition. One example is given in Fig. 1. The comparison with MSR is shown in Fig. 2, in which MSR produces less luminance enhancement than INDANE for the image that has a high-luminance background.

4. Conclusion

A new image enhancement algorithm has been proposed to improve the visibility of digital images. It has two separate processes: luminance enhancement and contrast enhancement. It is implemented with nonlinear transfer function and multi-scale convolutions. The enhanced images’ good quality has been confirmed.

5. References
