Adaptive Color Image Enhancement based Geometric Mean Filter

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ABSTRACT
In this paper, an adaptive color image enhancement based on geometric mean filter is proposed. The contrast of the color image is enhanced by using saturation feedback from saturation components and incorporating spatial information into luminance components. Hue is preserved in order to avoid color distortion. The adaptive luminance enhancement is achieved by using a geometric mean filter in place of arithmetic mean filter since arithmetic mean filter tends to lose image detail such as edges and sharpness when compared to geometric mean filter. The traditional algorithm uses the arithmetic mean filter which smoothes local variations of luminance and saturation. The reconstructed quality of image using this scheme is generally not satisfactory. In the proposed method, geometric mean filter has been adopted that achieves very good quality reconstructed images, far better than that possible with the arithmetic mean filter. It not only enhances poor quality images but also solves the problem of gray world violation. The experimental results show that color images enhanced by this algorithm are clearer, vivid and efficient.

Categories and Subject Descriptors
I.4.3 [**Image Processing and Computer Vision**]: Enhancement-*Filtering*.

General Terms
Algorithms, Experimentation, Security.

Keywords
Color Image Enhancement, HSV, Geometric Mean Filter, Saturation Feedback.

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1. INTRODUCTION
Image enhancement [1] refers to accentuation, sharpening of image features such as edges, boundaries, or contrast to make a graphic display more useful for display and analysis. Image enhancement includes gray level and contrast manipulation, noise reduction, edge crispening and sharpening, filtering, interpolation and magnification, pseudocoloring, and so on.

Nowadays color image enhancement [2] is becoming an increasingly important research area. Color image enhancement may require improvement of color balance or color contrast in a color image. Enhancement of color images becomes a more difficult task not only because of the added dimension of the data but also due to the added complexity of color perception. There exist a number of techniques for color image enhancement such as intensity transformations, histogram equalization, power law transformations etc. These techniques are outlined in the following sections.

The color image enhancement can be classified into two categories according to the color space:

(i) Color Image Enhancement Based on RGB Color Space

The algorithms mainly used in RGB space are histogram equalization, intensity transformations, homomorphic filtering and retinex. The RGB color representation is the most widely used color space. These primary colors can be combined to produce enormous number of secondary colors. Although it is possible to enhance a digital real color image by applying existing grey-level image enhancement algorithms to each red, green and blue channel, the resulting image may not be enhanced optimally. The algorithm is applied to individual channels without considering the correlation between R, G, and B component of the image. RGB color space has weakness in representing shading effects or rapid illumination changing. In order to solve this problem, we consider converting an image from RGB space to other spaces.

(ii) Color Image Enhancement Based on Transformed Space
These types of algorithms [3] transform images from RGB color space into other spaces such as HSV, YCbCr, YUV, Lab, etc. In RGB space, the pixel intensity of a color image is not separated from the color. Other spaces such as HSV discriminate between color and intensity and hence these spaces reconstruct better

images than is possible with the RGB space. Therefore, the color image should be transformed from RGB space to other space. In this work, HSV color space is chosen since it offers good image enhancement.

1.1 HSV color space

The HSV color space [4] is based on cylindrical coordinates. The HSV model defines a color space in terms of three constituent components. Hue represents type of color such as red, blue, or yellow that ranges from 0 to 360 degrees. Saturation is the vibrancy of color that ranges from 0 to 100%. The lower the saturation of a color, the more gray the image looks and more faded the color appears. Value (intensity) is the brightness of the color that ranges from 0 to 100%. HSV space is also known as hex cone color model; however, the human color space is a horse-shoe-shaped cone. In addition, color system is considerably closer than the RGB system to the way in which a human experiences and describes the color sensations. The HSV color space is widely used to generate high quality computer graphics. In simple terms, it is used to select various colors needed for a particular picture. The relation between HSV and RGB is defined in Eqn. (1) to (3).

$$H = \cos^{-1}\left(\frac{\frac{1}{2}[(R-G)+(R-B)]}{\sqrt{(R-G)^2+(R-B)(G-B)}} \right) \tag{1}$$

$$S = 1 - \frac{3}{R+G+B}[\min(R,G,B)] \tag{2}$$

$$V = \frac{1}{3}(R+G+B) \tag{3}$$

Gang Song et al. [5] proposed an adaptive color image enhancement based on human visual properties in HSV space. The color images enhanced by this algorithm have richer color, clearer details, and better visual effect. However, the image enhancement is based on arithmetic mean and variance computation. Although an arithmetic mean filter smoothes local variation in an image and noise is reduced to some extent, it actually results in blurring of the image. In addition, the arithmetic mean filter tends to lose image details such as edges and sharpness. Doo Hyun Choi et al. [6] proposed color image enhancement based on single scale retinex with a JND based non-linear filter in HSV space. They used a Gaussian pyramid to estimate the global illumination and JND-based nonlinear low pass filter to estimate local illumination in an image. This method provides better performance for color image enhancement over the conventional histogram equalization and single scale retinex. However, saturation and value component of the images are enhanced only if the image is illuminated by white light.

A new color image enhancement algorithm based on human visual system based on adaptive filter is proposed by Xinghao Ding et al. [7]. The algorithm utilizes color space conversion to obtain a much better visibility. This method has better effectiveness in reducing halo and color distortion. However, the algorithm may not be efficient from computation point of view. Hongqing Hu et al. [8] proposed an improved retinex image enhancement algorithm. The algorithm has very good performance in color constancy, contrast and computational cost. In this method, halo artifacts are reduced but not satisfactory.

Daniel J Jobson et al. [9] has proposed Multi-Scale Retinex (MSR), which fills the gap between color images and the human observation of scenes. The enhanced image has good dynamic range compression and color constancy. The reconstructed images are favorable for human visual perception and improve contrast. However, the method fails to produce good color rendition for a class of images that contain violations of the gray world assumptions. The MSR may give somewhat reduced halo artifact compared to the Single Scale Retinex (SSR). It, however, cannot remove the halo artifacts completely. In order to minimize the halo artifact in the SSR and MSR, Ogata et al. [10] proposed an MSR that adopts a nonlinear low pass filter (LPF) called as ε-filter. The ε-filter substitutes a pixel with the center pixel within the filter window if the brightness difference of the two pixels is greater than a threshold. Xiong Jie et al. [11] proposed a color image enhancement in HSV space. The algorithm provides good color rendition since it preserves hue. In addition, saturation channel is enhanced by Butterworth high pass homomorphic filter and value channel is enhanced by multiscale Gaussian high pass homomorphic filter. This paper proposes a new method to fix on the cutoff frequency of the high pass filter. The algorithm provides real color image enhancement compared to other methods. However, the computation is complex.

This paper is organized as follows: Section 2 gives a brief review of luminance enhancement based on adaptive saturation feedback. Section 3 describes the proposed Adaptive Color Image Enhancement based on Geometric Mean Filter (AGMF). Section 4 provides results and discussions. Finally conclusion is presented in Section 5.

2. LUMINANCE ENHACEMENT BASED ON ADAPTIVE SATURATION FEEDBACK

The contrast of the color image can be enhanced by feeding back the high frequency spatial information from saturation component into the luminance component. The saturation feedback algorithm proposed by Strickland et al. [12] can be expressed as:

$$V_{enh}(x,y) = V(x,y) + k_1[V(x,y) - \overline{V}(x,y)] - k_2[S(x,y) - \overline{S}(x,y)] \tag{4}$$

where V and S represent the luminance and saturation component of the original image and V_{enh} is the luminance component of the enhanced image. The barred quantities represent the blurred versions of the respective components; k_1 and k_2 are scaling constants which are real numbers. The negative sign preceding the third term reflects the use of negatively scaled saturation data. The terms within the square bracket in Eqn. (4) represents unsharp masking (USM) of luminance and saturation component. The USM produces simultaneous effects: an increase in perceived contrast along with increase in perceived sharpness. For $k_2=0$, the operation performed is traditional USM but for $k_2>0$, a cross component USM results. The two key drawbacks of Eqn. (4) are: (i) it makes no effort to restrict the feedback of structurally incongruent image information and (ii) it employs fixed-polarity feedback of the saturation data. Thomson et al. [13] proposed a simple sign change in Eqn. 4 as shown by Eqn. (5) to improve the reconstruction adaptively.

$$V_{enh}(x,y)=V(x,y)+k_1[V(x,y)-\overline{V}(x,y)] \\ +k_2[S(x,y)-\overline{S}(x,y)]\times\rho(x,y) \quad (5)$$

The local correlation of luminance and saturation data exhibit spatially varying polarities. The feedback of saturation information having improper polarity leads to contrast reversals and the loss of luminance information. The adaptive luminance enhancement now includes a new factor ρ(*x, y*). The ρ(*x, y*) known as local correlation coefficient of *V* and *S* is defined by Eqn (6):

$$\rho(x,y)=\frac{\sum_{(i,j)\in w}[V(x,y)-\overline{V}_w(x,y)][S(x,y)-\overline{S}_w(x,y)]}{\sqrt{\sigma_v^2(x,y)\sigma_s^2(x,y)}} \quad (6)$$

where w represents a 3×3 or 5×5 pixel window centered about pixel (*x, y*) in both luminance and saturation component images. The coefficient ρ(*x, y*) simultaneously effects local mean and local variance of the image. The local means and scaled local variances of the component images are also computed using the same window. The local mean and local variance for both luminance and saturation are given by Eqns. (7) to (10).

$$\overline{V}_w=\frac{1}{mn}\sum_{(i,j)\in w}V(i,j) \quad (7)$$

$$\overline{S}_w=\frac{1}{mn}\sum_{(i,j)\in w}S(i,j) \quad (8)$$

$$\sigma_v^2(x,y)=\sum_{(i,j)\in w}[V(i,j)-\overline{V}_w]^2 \quad (9)$$

$$\sigma_s^2(x,y)=\sum_{(i,j)\in w}[S(i,j)-\overline{S}_w]^2 \quad (10)$$

The algorithm makes the best of the local correlativity of the luminance and saturation component. It adjusts the luminance component adaptively and makes some effects. The local correlation coefficient of Eqn. (6) is well suited for saturation feedback. The values of ρ(*x, y*) lie in the interval [-1, 1]. The magnitude of ρ(*x, y*) determines how appropriate the saturation data is at a given location. Uncorrelated regions are considered to be inappropriate and are scaled back accordingly. The sign of ρ(*x, y*) sets the polarity of the saturation feedback, thus enabling it to adapt to the local data. The scaling constant, $k_1<1$, image details are not sharpened and for $k_1>1$, the image details are sharpened but the noise get enhanced contemporarily. This implies that algorithm is sensitive to image noise. In addition, the arithmetic mean computed for both luminance and saturation smoothes local variations of an image resulting in blurring.

3. PROPOSED COLOR IMAGE ENHANCEMENT

This paper proposes a new adaptive color image enhancement based on geometric mean filter [AGMF] in order to overcome the drawbacks of the Gang Song et al. [14] algorithm. Geometric mean filter [1] achieves smoothing comparable to the arithmetic mean filter. In addition, geometric mean filter tends to lose less image detail as compared to arithmetic mean filter. The restored pixel is given by the product of the pixels in the subimage window, raised to the power of (1/mn). The geometric means for luminance and saturation may be expressed by Eqns. (11) and (12):

$$\overline{V}'_w=\frac{1}{mn}\left(\prod_{(i,j)\in w}V(i,j)\right)^{\frac{1}{mn}} \quad (11)$$

$$\overline{S}'_w=\frac{1}{mn}\left(\prod_{(i,j)\in w}S(i,j)\right)^{\frac{1}{mn}} \quad (12)$$

where m = 3 and n = 3 for 3×3 window.

The new local variance for luminance and saturation are now expressed as:

$$\sigma'^2_v(x,y)=\sum_{(i,j)\in w}[V(i,j)-\overline{V}'_w]^2 \quad (13)$$

$$\sigma'^2_s(x,y)=\sum_{(i,j)\in w}[S(i,j)-\overline{S}'_w]^2 \quad (14)$$

Further, the local correlation coefficient of luminance and saturation follows the Eqn. (15).

$$\rho'(x,y)=\frac{\sum_{(i,j)\in w}[V(x,y)-\overline{V}'_w(x,y)][S(x,y)-\overline{S}'_w(x,y)]}{\sqrt{\sigma'^2_v(x,y)\sigma'^2_s(x,y)}} \quad (15)$$

The new luminance enhancement along with saturation feedback is given by the Eqn. (16).

$$V'_{enh}(x,y)=V(x,y)+k_1[V(x,y)-\overline{V}'(x,y)] \\ -k_2[S(x,y)-\overline{S}'(x,y)]\times\rho(x,y) \quad (16)$$

The human vision is sensitive to the noise of the smooth parts in an image than to the noise in detailed parts. In order to enhance the local contrast more in the edges and less in the smooth area, the coefficient k_1 is made proportional to change in the area of the image. The gradient of the luminance component is obtained using Sobel operator and is given by the Eqn. (17).

$$\nabla V(x,y)=V(x+1,y+1)+2V(x+1,y)+V(x+1,y+1) \\ -(V(x-1,y-1)-2V(x-1,y)-V(x-1,y+1) \quad (17)$$

The Sobel operator not only smoothes the noise but also emphasizes the details of the edges in an image.

The luminance enhancement with saturation feedback now can be expressed as Eqn. (18).

$$V'_{enh}(x,y)=V(x,y)+k(x,y)[V(x,y)-\overline{V}'(x,y)] \\ -k_2[S(x,y)-\overline{S}'(x,y)]\times\rho'(x,y) \quad (18)$$

In order to improve the whole effect of color image with brighter and richer color besides the luminance enhancement, it is also required to enhance saturation. In this work, hue is preserved in order to avoid color distortion. The saturation component is enhanced by stretching its dynamic range to get rich color display. It is a known fact that prints and display devices respond according to a power law and hence we use the same power law to stretch the saturation component of an image. The mathematical model for saturation component enhancement is given by Eqn. (19).

$$S_{\text{enh}} = S^{\gamma} \tag{19}$$

where S represents original saturation component and S_{enh} is the enhanced saturation component. The gamma is the stretch coefficient which determines the degree of saturation enhancement. When gamma is more, the less saturated the image looks and, lower the gamma, the more saturated the image looks. The value of gamma was arrived at a value of 0.77 after conducting elaborate experiments.

The proposed new algorithm for color image enhancement is as follows:

1. Read the Color Image.
2. Transform Color Image from RGB color space to HSV space.
3. Separate combined HSV into individual components *H*, *S* and *V*.
4. Using Eqn. (18), the luminance component is adaptively enhanced and the saturation component is stretched using Eqn. (19). Hue remains unchanged in order to avoid color distortion.
5. Combine separated components of *H*, *S* and *V* into composite HSV.
6. Transform back HSV space to RGB color space.
7. Display the enhanced color image.

4. RESULTS AND DISCUSSION

The developed algorithm presented in the previous section was coded using Matlab Version 8.0. The experiment was conducted by considering three poor quality test images. In this work, window size was chosen as 3×3 since the image looks better and more colorful than the original image.

Figure 1(a) shows the original "Tractor" image of size 512×512 pixels. Figure 1(b) shows the same image enhanced based on histogram, equalized separately for R, G, and B channels. The color distortion is perceivable in the histogram enhanced image of Figure 1(b). Figure 1(c) shows the image enhanced based on arithmetic mean filter proposed by Gang Song et al. [14].

In order to evaluate the performance of the proposed method, we present contrast enhancement performance [15], luminance enhancement performance [16] and peak signal to noise ratio (PSNR). The contrast enhancement performance *C*, Luminance enhancement performance *L* and PSNR is evaluated using the following Equations.

$$C = \frac{\sigma_{out} - \sigma_{in}}{\sigma_{in}} \tag{20}$$

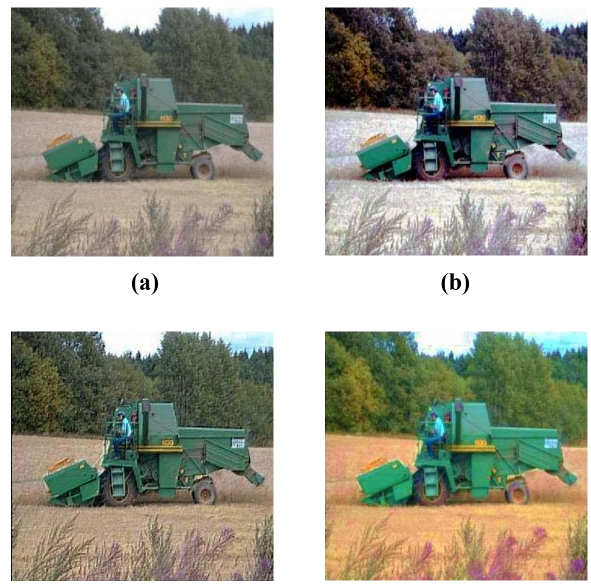
$$L = \frac{I_{out} - I_{in}}{I_{in}} \tag{21}$$

$$PSNR = 10 \log_{10} \left[\frac{255^2}{MSE} \right] \tag{22}$$

The Mean Square Error (MSE) is given by

$$MSE = \sum_{x=1}^{p} \sum_{y=1}^{q} \frac{\left(E(x,y) - I(x,y) \right)^2}{pq} \tag{23}$$

where σ_{out} is variance of the luminance value of the output image, σ_{in} is variance of the luminance value of the input image, I_{out} is the mean of the luminance value of the output image, I_{in} is the mean of the luminance value of the output image, *E(x, y)* is the enhanced gray pixel at position *(x, y)*, *I(x, y)* is the original gray pixel at position *(x, y)* and, p and q denote the size of the gray image.



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

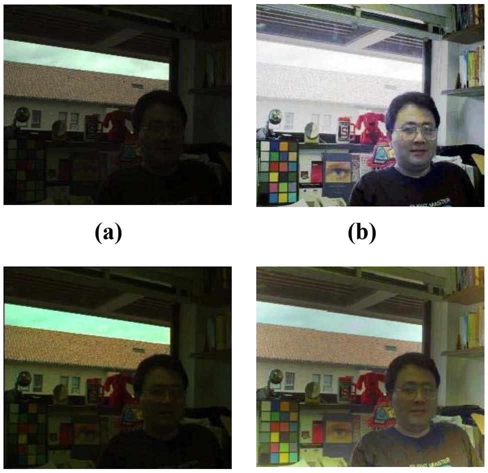
Figure 1. Image Enhancement Results of Tractor (a) Original Image (b) Image Enhanced using Histogram Equalization (c) Image Enhanced based on the algorithm proposed in Ref. [14] (d) Image Enhanced using the proposed AGMF Method

It is clear that, the contrast enhancement performance of the proposed method is good as compared to other methods. The luminance of the histogram equalization has increased; hence the image looks over enhanced leading to color distortion. The proposed method has better PSNR as compared to other methods.

In order to enhance the quality of the original image, the proposed method uses a value of 0.77 for gamma and window size is chosen as 3×3. In our method, the value of scaling constant k_2 is taken as 2 for better visual effects. Figure 1(d) shows the image enhanced using AGMF method. The adaptive color image enhancement based on geometric mean filter provides better results compared to other methods. Figure 2 shows experimental results of person having different colored objects as background.

Table 1. Performance Comparison

Parameter	Histogram Equalization Method	Gang Song et al. of Ref. [14] Method	Proposed AGMF Method
Contrast	0.2815	0.3826	0.6236
Luminance	0.5342	0.4215	0.4178
PSNR	34.7	32.3	32.5



(a) (b)

(c) (d)

Figure 2. Experimental Results of Person (a) Original Image (b) Image Enhanced using Histogram Equalization (c) Image Enhanced based on the algorithm proposed in Ref. [14] (d) Image Enhanced using the proposed AGMF Method

Figure 3. Reconstruction of Images Using Adaptive Geometric Mean Filter Method
First Column: Original Images of size 512×512 pixels
Second Column: Images Enhanced Using Histogram Equalization.
Third Column: Images Enhanced Using Proposed GMF method

Table 1. shows the performance comparison for Tractor image shown in Figure. 1.

In order to show the proposed method in more detail, the algorithm is tested with other test images. The first column of Figure 3 shows three different original color images. The second column of Figure 3 shows the same images enhanced by conventional histogram equalization of R, G and B channels in RGB color space. The result shows that histogram equalized images suffer from color distortion. The last column of Fig. 3 shows the images enhanced by proposed luminance enhancement algorithm based on saturation feedback.

Experimental results show that the color image enhancement based on the proposed Adaptive luminance and saturation feedback offers much better enhanced images than that of other methods. The reconstructed images offer richer color, clearer details and higher contrast.

5. CONCLUSION

In this paper, adaptive color image enhancement based on geometrical mean filter was proposed. In this method, hue is preserved in order to avoid color distortion. The adaptive luminance enhancement is achieved by using geometrical mean filter since geometric mean filter tends to lose less image detail as compared to arithmetic mean filter. Geometric mean filter achieves smoothing comparable to the arithmetic mean filter. The experimental results show that color images enhanced by the proposed algorithm are clearer, more vivid and more brilliant than that achieved by arithmetic mean filter methods. The performance of the proposed method is verified by applying contrast enhancement performance, luminance enhancement performance and peak signal to noise ratio. Currently, research work is under progress for enhancement of aerial images and medical images.

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