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Image Contrast Enhancement by Homomorphic Filtering based Parametric Fuzzy Transform

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Abstract

In this paper, a new image contrast enhancement technique by taking the advantages of Homomorphic decomposition and fuzzy transform is been employed. For increasing the clarity of the image generally, histogram or Retinex theory based algorithms were used. These procedures worked on enhancing the reflectance layer by ignoring illumination, which is not a better strategy and leads to poor results. Fuzzy based image enhancement approach makes use of illumination by omitting reflectance. In our proposed algorithm, Homomorphic decomposition is used for getting the exact illumination image from the value layer of HSV (Hue, Saturation, Value) image. Next, the parametric fuzzy transform is employed to enhance the image by updating its membership functions and thereby smoothing the luminance layer. Finally, a weighted image is generated by pixel neighborhood property for preserving the image details. The results show the profoundness of the algorithm in terms of its clarity and complexity even for nonuniform illumination images.

Keywords:; Image filtering; Contrast Enhancement; Non-Uniform Illumination; Homomorphic decomposition; Reflectance; Fuzzy Transform.

1. Introduction

Image enhancement refers to expand the representation of an image for greater perception by human viewers or to

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present more reliable data to different image processing algorithms. Primarily images weaken with blurring, noise, low contrast when captured with low intensity or by other environmental conditions. There are various image enhancement methods befalling in either the spatial domain which explore on pixel values or frequency domain methods which make uses of Fourier transform, however to state which is better it depends on the observation as there is no method or quantitative standard. if the image has nonuniform illumination sadly, many algorithms displease or show no change in the enhanced image. Though notable work has carried out by Histogram or Retinex based approaches for enhancement of nonuniform illumination images.

Due to the simplicity, efficiency and low computational cost histogram equalization have gained attention among several image enhancement techniques. Histogram Equalization (HE) process makes usage of dynamic range intensity values by stretching and flattening over the entire spectrum. Normally this method is used to improve the global contrast in case of the image pixels represented by close contrast values [1]-[7]. Histogram equalization faces two major shortcomings first one is unwanted artifacts which makes the algorithm not suitable for consumer electronics like televisions. Ibrahim and Kong addressed this problem in Brightness Preserving Dynamic Histogram Equalization (BPDHE) method [2] where input histogram is smoothed with Gaussian filter followed by partitioning based on its local peaks later each distribution will be allocated to a new dynamic range. Conventional HE is operated separately to these intensity distributions, thereby rectifying the issue of histogram equalization artifacts. Later this method is been improved to Brightness preserving dynamic fuzzy histogram equalization [3] by incorporating fuzzy statistics of images in BPDHE approach. However, both these techniques fail in the case of nonuniform illumination images.

The other shortcoming of HE comes when there is high spatial variation in image contrast. To overcome this Celik and Tjahjadi proposed an algorithm for contrast enhancement of the given image using the concept of interpixel contextual information [4]. Histogram equalization never gained importance due to the above reasons and high computational cost. In 1971 Land and McCann introduced to the concept of Lightness and Retinex Theory [8]. Retinex theory states that an image can be viewed as the product of reflectance and illumination as shown below

$$I(x,y) = R(x,y) * L(x,y) \tag{1}$$

where $L(x,y)$ is the illumination and $R(x,y)$ is the reflectance of the image $I(x,y)$ at pixel location (x,y). Illumination depends on the light source whereas reflectance depends on the imaged objects. As per the Retinex theory of image enhancement process firstly estimation later normalization of the illumination but extracting the illumination of the image is quite challenging [9]. Y. Gao, H. Hu, B. Li, and Q. Guo [11] presented a naturalness preserved illumination estimation algorithm with the help of combined approach of edge-preserving filter and box filter which achieves a range of the estimated illumination. Lightness-order-error (LOE) measure as shown in [12][13] is used to estimate the naturalness of the image without destroying the naturalness however, the latter approach has a low computational cost. For non-uniform illumination images, apart from the conventional Retinex approach an intrinsic image decomposition-based image enhancement technique is been developed [13][14]. Intrinsic Decomposition utilizes well-known Block Matching and 3-D filtering (BM3D) denoizing filter for image enhancement which includes slight flicker in the enhanced image. Finally, these patches are corrected with the help of contrast limited adaptive histogram equalization (CLAHE) algorithm [14][15]. Anyhow this method has its own set of drawbacks as stated[14] one of them is utilizing the decomposition model directly for other than contrast enhancement, like surface re-texturing and object inclusion, may not give better results.

The uncertainty in Retinex-based models as discussed above is majorly due to two reasons, estimating the illumination exactly which has to be adjusted or corrected and second reason is finding the image decomposition boundary. Hasikin and Isa in their research work on Adaptive fuzzy contrast factor enhancement technique for low contrast and nonuniform illumination images deals with ambiguity in the Retinex algorithm, by addressing it to the nonuniform illumination images [16]. However, threshold based brightness preservation technique may lead to unsatisfactory outcomes for the nonuniform illumination. Improvements were made to fuzzy rule-based model by Perfilieva to Fuzzy transform technique and its inverse [17][18] which is more proper in course of computational cost for image processing applications. Fuzzy Transform was further relatively improved by Stefanini [19]–[21]. Fuzzy Transform property of image smoothing helps in the enhancement of the original image. Detailed study on Fuzzy Transform are discussed in [17]-[21].

In our proposed approach, parametric fuzzy transform (pFT) is used for smoothing the image more precisely luminance is done with fuzzy partitions. For illumination adjustment without image decomposition, the V-Component of Hue, Saturation and Value layered image is taken into consideration as shown in the Fig.1, as observed more color details are provided this V-layer.

Fig. 1. (a) RGB Image; (b) HSV Image; (c) H layer; (d) S layer; (e) V layer;

Next sections of the paper will be arranged as follows proposed method discussing on Homomorphic decomposition for extraction of illumination and reflectance and the Fuzzy Transform for image smoothing will be discussed in Section-II. Results and observations are shown in Section-III Finally Section –IV gives the conclusion.

2. Proposed Method

Following are the steps carried out in the implementation of the proposed algorithm

- The RGB original image is converted into HSV image.
- Homomorphic filtering applied to the value layer of HSV plane for getting the illumination and reflectance of the image.
- Then to the illumination component, pFT is applied resulting in smooth transformed image Lft.
- Finer details are obtained by pixel neighborhood property to get the weighted V channel (Vw).
- Ie is obtained by combining smoothed image (Lft) with weighted image details (Vw)
- Finally the HSV color Space with new value layer is convereted to RGB image.

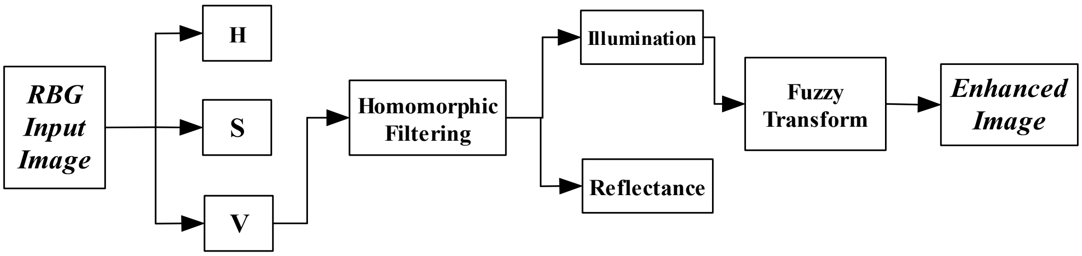

Fig.2. Proposed algorithm flow diagram

As shown in the above figure of the proposed method, the RGB image is converted into HSV out of which V layer is selected for further processing. Homomorphic filtering is used for the extraction of exact illumination in the image that will be discussed next.

2.1. Homomorphic Filtering

For getting illumination within the image is a challenging task and to do this Homomorphic decomposition is one of the best methods. This is a frequency domain filtering process used for the separation of the illumination and reflectance components [22]-[25]. Every image is a function of two components (1) the amount of light incident on the scene in an image is named as the illumination component (2) and the reflectance component is the light reflected by the scene. For an image $f(x, y)$ at a pixel location (x, y) the illumination component $i(x, y)$ and the reflectance component $r(x, y)$ is represented as shown in the equation below [22].

$$f(x,y) = i(x,y) \bullet r(x,y) \quad (2)$$

The transformation function such as Fourier transform is used to convert the spatial domain image to the frequency. But, before to transformation logarithmic function is applied to the equation (2) wherein the product is changed to the sum of the components as given below

$$\ln\left(f(x,y)\right) = \ln\left(i(x,y).r(x,y)\right) = \ln\left(i(x,y)\right) + \ln\left(r(x,y)\right) \quad (3)$$

Applying Fourier transform to the equation gives

$$F(z(x,y)) = F(\ln i(x,y)) + F(\ln r(x,y))$$
$$Z(u,v) = F_i(u,v) + F_r(u,v) \quad (4)$$

where $Z(u,v), F_i(x,y)$ and $F_r(u,v)$ are the Fourier transform of $Z(x,y)$, $\ln i(x,y)$ and $\ln r(x,y)$ respectively.

As per the Homomorphic filtering as shown in the Fig.3 the Fourier transformed image obtained is given to high pass filter H_{ky} given by

$$H = (rH - rL) \times H_{ky} + rL$$

rH and rL are the filter coefficients which effect reflectance and illumination respectively.

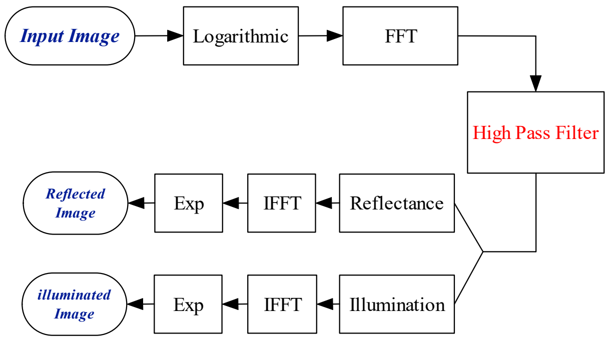

Fig.3. Homomorphic Filtering Process

Followed by the inverse Fourier transform is applied separately then the logarithmic effect is reversed employing the exponential function. From the obtain illumination and reflectance images fuzzy transform is applied to the illumination image as discussed below.

2.1. Fuzzy Transform for Smoothing.

Fuzzy sets are constructed using different segments/features within an image. By applying these fuzzy sets using a suitable method among all available approaches that recognize, describe and process the images is known as fuzzy image processing. The design and processing depend on the chosen fuzzy procedure and on the objective of the algorithm. The drawback of Retinex-based algorithms in image decomposition for estimating the exact illumination is removed by homomorphic filtering. To deal with the problem of decision boundary for nonuniform illumination, fuzzy transform is the best mechanism. An adaptive fuzzy contrast factor based brightness preserved image enhancement method based on thresholding as given by Hasikin and Isa [16] doesn't give good results under nonuniform illumination. The extension from the fixed fuzzy rule-based system to the more suitable method in terms of computational cost known as fuzzy transform (FT) was developed by Perfilieva[17][18]. Further improvements to the fuzzy transform were done by Stefanini out of which Fuzzy transform and smooth functions [21] is used in our approach [19]–[21].

To enhance the illumination image of homomorphic decomposition, mostly Gaussian is been applied to smooth the luminance distribution. In our proposed algorithm Gaussian filtering is replaced with parametric fuzzy transform as proposed by Stefanini [19]-[21]. The fuzzy partitions are done on the illumination image derived from the V-layer of HSV color space by which contrast enhancement is achieved.

For illumination image of size *(x, y)* parametric fuzzy components are obtained from the equation as shown below.

$$L_{ft} = \frac{\sum_{y=1}^{M}\sum_{x=1}^{N} A(x)B(y)L(x,y)}{\sum_{y=1}^{M}\sum_{x=1}^{N} A(x)B(y)} \tag{5}$$

where A(x), B(y) are the membership grades that adjust to the illumination image of homomorphic filtering. The value of the fuzzy component depends on the features of the fuzzy partitions A & B in x and y coordinates respectively. Perfilieva's [17] used triangular fuzzy partitioning which is been is modified by including a parameter k in our proposed method as shown below.

$$A(x) = \begin{cases} \frac{k(x-a)}{m_1 - a}, & a \le x \le m_1 \\ \frac{(1-k)(x-m_1)}{b-m_2} + k, & m_1 \le x \le b \\ \frac{(k-1)(x-m_2)}{m_2 - b} + k, & b \le x \le m_2 \\ \frac{k(x-c)}{m_2}, & m_2 \le x \le c \\ 0.0001, & otherwise \end{cases} \tag{6}$$

Next, a weighted image V_w is formed to store the image details by applying the Hadamard operator (◦) on weight (w) and Illumination image, as in equation below

$$V_w = \frac{\sum_{x}^{M}\sum_{y}^{N} w_{xy} \circ L(x,y)}{\sum_{x}^{M}\sum_{y}^{N} w_{xy}} \tag{7}$$

Using the property of neighborhood similar or dissimilar weights are assigned to the pixel. Directional filters help in getting the pixel similarity in horizontal, vertical or diagonal directions. In the pixel neighborhood with large dissimilarity is given the highest weight and the similar neighborhood is given least. Then, the value layer (Ie) of enhanced image is computed by smoothed illumination obtained in equation 5 with weighted image details of equation 7 as given below

$$I_e = L_{ft} + V_w \tag{8}$$

The enhanced V layer is replaced and finally, HSV image is transformed back to RGB. Originality and Color of the image characterized by saturation and hue are not changed hence they are same as the original image.

3. Results and Discussion

The proposed method is implemented on the MATLAB for low contrast nonuniform illumination RGB images. As shown in the Fig.4 column 1 are the input images and column 2 are the enhanced images, results show that a good enhancement is achieved. The first image is a low contrast non uniform illumination image where the finer details are been brought up in the image are clearly visible. The second image is a photo frame captured under shadow making it dark for which the contrast in the area of the shadow is been enhanced making it clearer visibility of the persons seen in the photo frame. Third is the challenging image which seems to be enhanced but after applying the proposed algorithm the it clearly shows more finer details are been brought up.

To carry out the image enhancement the after changing the color space the Value layer image was taken for into processing keeping the Hue and Saturation with no change. By Homomorphic filtering illumination and reflectance components are been derived. Illumination correction by smoothing the image using parametric fuzzy transform is carried out, finally the enhanced V layer image is attached with hue and saturation then it is converted back to the RGB image as seen in the column 2 of Fig. 4.

Fig.4. Results of Contrast Enhancement in column 2 and input images in column 1

4. Conclusion

A new contrast enhancement of nonuniform illumination images has been carried out efficiently using our proposed parametric Fuzzy Transform algorithm. The exact amount of illumination is determined by the means of Homomorphic decomposition to which luminance adjustment and the pixel weighting make it more efficient. The results obtained show that it is a simple, effective, less complex method for image contrast enhancement. On comparison with other related algorithms the proposed method produces better results in terms of the brightness, contrast and more details are clearly visible.

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