Color Image Enhancement Depending on Fuzzy Logic and Nonlinear Transform

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Abstract. Color image enhancement considered one of the challenging fields in image processing category. The nonlinear function based on a fuzzy logic algorithm is developed within this paper to enhance image color. The suggested algorithm used sigmoid mapping and the membership function which relied on histogram analysis to enhance image contrast. The results of the suggested algorithm compared with fuzzy logic (square method), fuzzy logic (cubic method), Histogram Equalization and Multi-Scale Retinex. Different criteria used to evaluate the performance of the presented algorithm like Mean-S, Mean-H, nature image quality evaluator, Lightness Order Error and entropy. The evaluated criteria show the suggested algorithm is better in color enhancement compared with the other methods.

Keywords: image enhancement, fuzzy logic, membership function, Nonlinear Transform, histogram equalization.

1. Introduction
Image enhancement gained impetus from last few decades and has a great significance. The hidden details or the significant enhancement to the contrast of an image amelioration is necessary and main purpose in image enhancement field[1]. To improve an image brightness, it is necessary to optimize its contrast, details and information of the image [2]. Low contrast has many causes, like bad lighting condition with missing the optimal setup of the camera [3], the image capture angle incorrect, the picture taken in a dusty atmosphere, or underwater imaging [4]. Contrast enhancement methods has a good performance in the homogenous grey level, but becomes difficult with non-homogenous background [5]. Image improvement is not limited to improving lighting only, but some image may be blur, so you need to deblur [6]. The computer vision and pattern recognition fields face challenges in the weak edges of the low contrast images.

A nonlinear intensity transformation algorithm proposed to improve the contrast of a typhoon cloud image [7]. Contrast enhancement is also used in forensics against the malicious persons who try to create a realistic composite image [8]. Histogram based image enhancement is very common and basic method which is still being used for the remote sensing images since they suffer from low contrast [9]. Dark image enhancement by locally transformed histogram proposed to find out the location of peaks and valleys from the histogram, but produces different types of noises such as unnatural effects [10, 11]. Discrete shearlet transform (DST) used for color image enhancement by converted color image into HSV [12]. A nonlinear filter power function (NFPF) used for color image enhancement by converted color image into YIQ and Color Restoration [13]. Human Visual System is used to enhance a gray-scale image [14].
This work presents color image enhancement using enhancement fuzzy logic and nonlinear transform based on a membership function. This can be achieved by design algorithms in Matlab software to convert a gray level domain into a fuzzy domain. The membership function is modified to fit the enhancement of low contrast images by means increasing the values of gray level at dark area.

2. Proposed Method

The fuzzy nonlinear membership function (FNMF) algorithm used to enhance the intensity and contrast color image. The proposed algorithm depending on intensity enhancement by using YIQ color space that mapping by nonlinear membership function.

The transformation of color image from basic red, green, and blue mode to YIQ mode is done using [15]:

\[
M_{for} = \begin{bmatrix}
0.299 & 0.587 & 0.114 \\
0.596 & -0.270 & -0.322 \\
0.211 & -0.253 & 0.312
\end{bmatrix}
\] (1)

where \(M_{for}\) is the image intensity.

Nonlinear transformations are used to improve low contrast; the nonlinear function is applied to adjust an illumination of curve. This function modifies the low values of pixels by increasing its values and reduce the high values of gray level to moderate the image. The resulted image with this method rewarded good details and appropriate clarity. Figure (1) shows the nonlinear membership function where low light improved according equation (3):

\[
I_{d}(x, y) = Y(x, y) / 255
\]

\[
Y_{t} = a \times b (I_{d}(x, y))^{1/2}
\] (3)

where \(a=0.1358\) and \(b=0.7589\) are a numerical stability factors.

![Figure 1. The introduced Nonlinear membership function.](image)

The next step, after completing the base of operations in the fuzzy domain (\(S_r(\mu_i)\)), which represents the last step in the fuzzy domain (F). Where \(S_r(\mu_i)\) being the successive applications given by [16]:

\[
S_r(\mu_i) = \begin{cases}
4\mu_i^3 & 0 \leq \mu_i \leq 0.5 \\
1 - 4(1 - \mu_i)^3 & 0.5 \leq \mu_i \leq 1
\end{cases}
\] (5)

Finally, Defuzzification operation applied for contrast enhanced image which calculated by:

\[
Y_e = F^{-1}(\mu_i)
\] (6)

Where \(F^{-1}\) is the inverse of the fuzzy domain resulting from stretching.
To restore the chromatic information of an image that owned an enhanced illumination component (Ye), this done by converting from YIQ color space to RGB color space by using [15]:

\[
M_{inv} = \begin{bmatrix}
1 & 0.956 & 0.621 \\
1 & -0.272 & -0.647 \\
1 & -1.060 & 1.703
\end{bmatrix}
\]

The Steps of FNMF algorithm are:

a. Read input image I (x, y).

b. Estimating the illumination of image I(x, y).

c. Normalizing the component of illumination (fuzzification) using equation (2).

d. Applying the Nonlinear function using equation (3).

e. Complete the base of operations in the fuzzy domain (\(S_r(\mu_i)\)) using equation (5).

f. Convert fuzzy domain into contrast enhanced image (Defuzzification) using equation (6).

g. Output is the enhancing image.

Detailed steps of the proposed algorithm to enhanced color images can be illustrated in figure 2.

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**Figure 2.** Flowchart of the FNMF algorithm.

This modification to calculate color values makes it possible to perform brightness correction by NMF algorithm in YIQ color space, while preserving the original color characteristics of the RGB space image.
3. Image Quality Evaluation

Image quality can be measured using different methods. The following methods are used to evaluate optimization results.

3.1. Entropy

Entropy can be understood as the image information of contents corresponding to the intensity level. Basically, when the value of entropy is bigger this indicates image keeps more detail of content. The entropy can be written as [17]:

$$\text{Entropy} = -\sum_i p(i) \log(p(i))$$  \hspace{1cm} (8)

where \( p(i) = \frac{n(i)}{N} \) means the likelihood of gray level prevalence and its range \( i \in [0-255] \) and \( N \) is the summation of image pixel number.

3.2 Mean Squared Error (MSE)

The MSE for hue (H) and for, saturation (S) can be written as:

$$\text{MSE}_H = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} (H_n(x,y) - H(x,y))^2$$  \hspace{1cm} (9)

$$\text{MSE}_S = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} (S_n(x,y) - S(x,y))^2$$  \hspace{1cm} (10)

Saturation (S) is the highest color in an image [18]. A lot of bright colours in a tested image referred to its highest value of intensity and can enhance using the average these values of all gray levels of an image.

3.3 Natural Image Quality Evaluator (NIQE)

Natural Image Quality Evaluator (NIQE) is an analyser of image quality which useful to measure deviation in the original image. It compares the tested image to a default model where the smaller value refers to a better perceptual quality.

The NIQE is outlined as the average local deviation field [19]:

$$\delta = \sum_{i,j} \sigma(i,j)$$  \hspace{1cm} (11)

where \( \sigma \) is the local sharpness, \( \sigma \) is the mean filter.

3.4 Lightness Order Error (LOE)

The lightness order error (LOE) is related to the lightness relation between the original image and the enhanced image to measure naturalness. The lightness \( L(x, y) \) of any tested image can be expressed as the highest three color bands value:

$$L(x, y) = \text{Max} (I(x, y, c))$$  \hspace{1cm} (12)

Where \( c \in \{r, g, b\} \), for gray level \( (x, y) \), the difference between of the original image \( I \) lightness and its enhanced value \( I_e \) can be written as [20]:

$$DS(x, y) = \sum_{i=1}^{m} \sum_{j=1}^{n} \left( U(L(x, y), L(i, j)) \Theta U(L_e(x, y), L_e(i, j)) \right)$$  \hspace{1cm} (13)

$$U(x, y) = \begin{cases} 1, & \text{for } x \geq y \\ 0, & \text{else} \end{cases}$$  \hspace{1cm} (14)

Where \( m \) and \( n \) are the image dimension, \( U(x, y) \) is the unit step function, \( \Theta \) is the convolution operator or exclusive [20]. The LOE can be summarized as [20]:

$$\text{LOE} = \frac{1}{m+n} \sum_{i=1}^{m} \sum_{j=1}^{n} DS(i, j).$$  \hspace{1cm} (15)

The definition of LOE tell us that the smaller value is better for the lightness.
4. Result and Discussion

In this experiment contrast and illumination are enhanced by image processing techniques. The objective analysis is consisting of five metrics i.e., entropy, Mean Squared Error for hue (MSEH), saturation (MSES), nature image quality Evaluator (NIQE) and Lightness Order Error (LOE). These analyses are used to compare for all studied methods: fuzzy logic (square method) (FZSM) [21], fuzzy logic (cubic method) (FZCM) [22], Histogram Equalization (HE) [1] and Multi-Scale Retinex (MSR) [23]. The studied four test images were of JPEG format. The images are Minaret.jpg, tire.jpg, girl.jpg and boy.jpg with resolution 360 × 236, 360 × 236, 283 × 432 and 283 × 432 respectively. All of these color images were processed using the MATLAB R2018a software package, and optimized using the proposed method. The enhancement methods have disadvantages like the image tested by FZSM has a little lighting and weak contrast as shown in figure 3(c)-6(c), and the image tested by FZCM has bad lighting and poor contrast. This is because this method shows the bright region more brightness and dark region more darkness as shown in figure 3(d)-6(d). Images that tested by HE method it has a color error as shown in figure 3(e)-6(e), and images that tested by MSR has a halo effect as shown in figure 3(f)-6(f).

Figure 3. Contrast enhanced Minaret.jpg images (a) Original image, (b) Enhanced image of FNMF, (c) Enhanced image of FZSM, (d) Enhanced image of FZCM, (e) Enhanced image of HE and (f) Enhanced image of MSR.

Figure 4. Contrast enhanced Tire.jpg images (a) Original image, (b) Enhanced image of FNMF, (c) Enhanced image of FZSM, (d) Enhanced image of FZCM, (e) Enhanced image of HE and (f) Enhanced image of MSR.

Figure 5. Contrast enhanced girl.jpg images (a) Original image, (b) Enhanced image of FNMF, (c) Enhanced image of FZSM, (d) Enhanced image of FZCM, (e) Enhanced image of HE and (f) Enhanced image of MSR.

Figure 6. Contrast enhanced boy.jpg images (a) Original image, (b) Enhanced image of FNMF, (c) Enhanced image of FZSM, (d) Enhanced image of FZCM, (e) Enhanced image of HE and (f) Enhanced image of MSR.
Table 1. Quantitative criteria to compare methods that used in figure 3 for the Minaret.jpg image.

| Enhancement Method | Quality Assessment |
|--------------------|--------------------|
| Entropy | MSE-S | MSE-H | NIQA | LOE |
| FNMF (b) | 7.645761 | 0.037050 | 8.09E-10 | 2.857353 | 0.380460 |
| FLSM (c) | 6.367064 | 0.090235 | 0.011987 | 4.116644 | 18.55351 |
| FLCM(d) | 5.535548 | 0.184531 | 0.015760 | 5.088080 | 18.55351 |
| HE (e) | 5.961693 | 0.040748 | 0.099630 | 3.158931 | 18.16083 |
| MSR (f) | 6.347080 | 0.118721 | 0.024821 | 3.641140 | 165.0946 |

Table 2. Quantitative criteria to compare methods that used in figure 4 for the Tire.jpg image.

| Enhancement Method | Quality Assessment |
|--------------------|--------------------|
| Entropy | MSE-S | MSE-H | NIQA | LOE |
| FNMF (b) | 7.751846 | 0.010931 | 1.72E-08 | 3.728848 | 0.415421 |
| FLSM (c) | 6.952619 | 0.077928 | 0.051255 | 3.763615 | 35.78020 |
| FLCM(d) | 6.389494 | 0.092554 | 0.059843 | 4.559557 | 35.78020 |
| HE (e) | 5.984124 | 0.017993 | 0.062336 | 3.897839 | 22.01948 |
| MSR (f) | 6.637885 | 0.043049 | 0.078971 | 6.008494 | 115.6542 |

Table 3. Quantitative criteria to compare methods that used in figure 5 for the girl.jpg image.

| Enhancement Method | Quality Assessment |
|--------------------|--------------------|
| Entropy | MSE-S | MSE-H | NIQA | LOE |
| FNMF (b) | 7.578489 | 0.066097 | 8.17E-10 | 2.685384 | 0.328144 |
| FLSM (c) | 5.901683 | 0.132808 | 0.002643 | 2.841501 | 2.269479 |
| FLCM(d) | 4.813481 | 0.212533 | 0.007332 | 3.331709 | 2.269479 |
| HE (e) | 5.971654 | 0.102196 | 0.111953 | 3.008012 | 8.689711 |
| MSR (f) | 6.319316 | 0.159503 | 0.074269 | 3.925618 | 173.6299 |

Table 4. Quantitative criteria to compare methods that used in figure 6 for the boy.jpg image.

| Enhancement Method | Quality Assessment |
|--------------------|--------------------|
| Entropy | MSE-S | MSE-H | NIQA | LOE |
| FNMF (b) | 6.854623 | 0.004493 | 4.95E-08 | 2.924018 | 0.140744 |
| FLSM (c) | 5.792135 | 0.191129 | 0.104252 | 3.240917 | 0.581928 |
| FLCM(d) | 5.073176 | 0.306096 | 0.104655 | 3.660885 | 0.581928 |
| HE (e) | 5.597017 | 0.05306 | 0.059608 | 3.685946 | 15.51732 |
| MSR (f) | 6.219689 | 0.135643 | 0.098459 | 4.192752 | 85.43846 |

Image quality test is better to use to show and compare some image characteristics with the enhanced image. Therefore, Entropy method used to evaluate the improvement of detail in the image, MSES, MSEH, NIQE and LOE.

Tables [1-4] represent the quantitative criteria for figures (3-6). The entropy values of the proposed method depending on table values considered the best because it has largest value and this shown in figure (3b- 6b). The MSES has the lowest value for the proposed method. This means it is maintained the saturation of the color but the happiness and MSR method is getting more valuable MSES. The FLSM and FLCM method, the MSES rate is high, which indicates that an unsaturated image has occurred. The MSEH for the proposed method has the most preserving the original colors of the improved image, because it possesses the very smallest value. While other methods show higher values of the MSEH ratio. NIQE indicates the percentage of distortion that leads to a reduction in image quality. The smallest value of this scale means better image quality, and it is noted that the proposed method has the smallest value. Finally, the LOE shows the proposed method has the smallest values that means the improved image has good lighting.
5. Conclusions
The images chosen in this paper contain poor contrast and unbalanced lighting. The introduced algorithm beat all the methods by means of improve the lighting and preserve its details for the tested images. The tested methods were globally used like fuzzy logic (square method), fuzzy logic (cubic method), Histogram Equalization and Multi-Scale Retinex. The comparison made between the proposed method and the other methods FZSM, FZCM, HE and MSR. The proposed method is better than the other methods due to the entropy criteria which give the best values (the higher value). The MSES, MSEH, NIQE and LOE on the contrary, the smaller values are better. Finally, the presented algorithm shows better results than other traditional methods by improving lighting and preserving the original colors, and showing an image that contains more detail and clarity (good contrast).

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