Lightness Enhancement by Fuzzy Logic Depending on Power Membership Function

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Abstract: Lightness problem considered one of the challenging fields in the image enhancement category. The power membership function based on a fuzzy logic algorithm is developed within this paper to enhance lightness in the color images. The suggested algorithm depends on nonlinear power function to enhance image contrast. The suggested algorithm compared with other algorithms such as 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 Square Error in the Saturation (MSES), Mean Square Error in the Hue (MSEH), nature image quality Evaluator and entropy. The evaluated methods show that the suggested algorithm improved the lightness and contrast better than the other methods.

Keywords: Image Enhancement, Fuzzy Logic, Membership Function, Adaptation Power Function, Histogram Equalization.

1. INTRODUCTION

Contrast is the distinction between bright and dark areas within the image. So, the lighting condition plays a vital role in object details appear clearly to be recognized and counted [1]. These details are shadows and bright lights that will facilitate produce a smart distinction within the image. To improve the image brightness, it is necessary to optimize its contrast and change the details and information of the image [2]. The low contrast means that the photographer did not use good lighting condition with missing the optimal setup of the camera, or the image is underwater [3]. Image quality can be improved by employ techniques to focus on hidden details of an image [4].

The brightness image improvement falls into two classes:
1- Indirect methods to enhance contrast.
2- Direct methods to enhance contrast.

The direct technique provided higher performance than the indirect method [5-8]. Kannan et. al. [9] presented two approaches for the enhancement of dark sports images. The methods are the fuzzy rule and sigmoid functions to enhance the dark and bright images. The contrast factors can be adjusted until a satisfactory result is obtained. Preethi et. al. [10] presented a membership function ramp used to enhance the visual appearance of the image so that maximum possible information could be extracted. The membership function is modified for dark and bright regions, but is left unchanged for the middle regions. Fuzzy image improvement depends on gray-level mapping from a gray plane into a fuzzy plane using a membership function.
2. Proposed Method

The fuzzy logic power membership function (FLPMF) algorithm is used to improve the contrast and brightness images at the same time. The input images are in Red Green Blue (RGB) format, sized R×C. The magnitude of every and each color channel is confined at intervals and vary [0 to 256]. The ambiguous logic methodology is employed to enhance the light and contrast within the irregularly illuminated image, since some areas have high illumination and others have low illumination. The power function is added as an organic function to treat those areas. The benefit is maintaining the moderate light areas, and reduce the intensity of light in the brighter regions as shown in Fig.(1) For example, the value in origin input equal to 0.1 and it becomes almost 0.3 to increase the brightness and reduced it in the high values like 1 to be 0.95.

![Power Membership Function](image)

Fig. 1. The introduced power membership function.

The Power membership function used to adjust an illumination curve. Where illumination enhanced according to [11]:

$$\mu_i = a + b x^c$$  \hspace{1cm} (1)

where $\mu_i$ is the membership value (output pixel intensity value), $a$, $b$, $c$ are numerical stability factors and its values are 0.0062, 0.9367, 0.5424 respectively [11], and $x$ represents the input pixel intensity value of the image.

After finding the membership function, we complete the base of operations in the fuzzy field ($S_r(\mu_i)$), which represents the last step in the fuzzy domain (F). Where $S_r(\mu_i)$ being the successive applications are given by [14]

$$S_r(\mu_i) = \begin{cases} 2\mu_i^2 & 0 \leq \mu_i \leq 0.5 \\ (1 - 2(1 - \mu_i)^2) & 0.5 \leq \mu_i \leq 1 \end{cases}$$ \hspace{1cm} (2)

Lastly, Defuzzification operation for contrast enhanced image is calculated by:

$$C = F^{-1}(\mu_i)$$ \hspace{1cm} (3)
The Steps of FLPMF algorithm are:

a. Read input image \( I(x, y) \) and extract the number of rows and columns \([R, C]\), and the pixel intensity of the input image.
b. Find max and min value of intensity.
c. Convert the pixel values of the image into fuzzy domain (fuzzification).
d. Disintegrate the input image into RGB layers.
e. Applying the power Membership function using equation (1) for each color layer.
f. Complete the base of operations in the fuzzy field \((S_f(\mu_I))\) using equation (2).
g. Convert fuzzy data into Contrast enhanced image (Defuzzification) using equation (3).
h. Output is enhancing an image.

The FLPMF is a method for low lightness image enhancement consists of three stages: (i) Disintegrate (RGB) color image to three Channel image (fuzzification), (ii) modifying intensity with contrast enhancement based on power Membership function, (iii) light enhancement (Defuzzification). The Flowchart of the proposed algorithm is shown in Fig. 2.
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 is defined as the maximum amount of information contained in the image. In general, when the value of entropy is bigger this indicates that the image retains more detail and more data content. The entropy defined as [12]:

\[
\text{Entropy} = - \sum_i p(i) \log p(i) \quad (4)
\]

Where \( p(i) = \frac{n(i)}{N} \) means the likelihood of intensity prevalence whose magnitude \( i \) ranges \([0-255]\) and \( N \) is the total pixel number of the image.

3.2 Mean Squared Error (MSE)

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

\[
\text{MSE}_H = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} (H_n(x,y) - H(x,y))^2 \quad (5)
\]

\[
\text{MSE}_S = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} (S_n(x,y) - S(x,y))^2 \quad (6)
\]

Saturation (S) is the highest color in an image[13]. A lot of bright colours in an image indicated by its highest value of intensity and can enhance by averaging the saturation of all intensities in 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 [17]

\[
\delta = \sum_i \sum_j \sigma(i, j) \quad (7)
\]

\( \delta \) is the local sharpness.

4. Result and Discussion:

In this paper, Illumination and contrast are improved by image processing techniques. The objective analysis is consisting of four metrics i.e., entropy, nature image quality evaluator (NIQE), Mean Squared Error for hue (MSEH) and saturation (MSES). These analyses are used to compare for all studied methods: fuzzy logic (square method) (FZSM) [15], fuzzy logic (cubic method) (FZCM) [16], Histogram Equalization (HE) [9] and Multi-Scale Retinex (MSR) [18]. The studied three test images were of JPEG format, and size of 360×236, and the personal image is 611×407 pixels. All of these color images were
processed using the MATLAB software, 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 Fig. 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 Fig. 3(d)-6(d). Images that tested by HE method it has a color error as shown in Fig. 3(e)-6(e), and images that tested by MSR has a halo effect as shown in Fig. 3(f)-6(f).

![Image](image.png)

Fig. 3. Image with its histogram (a) Original image, (b) Enhanced image of FLPMF, (c) Enhanced image of FZCM, (d) Enhanced image of FZCM, (e) Enhanced image of HE and (f) Enhanced image of MSR.
TABLE (1): QUANTITATIVE CRETIREA TO COMPARE METHODS THAT USED IN FIGURE 3

| Enhancement Method | Quality Assessment | Entropy | MSE-S | MSE-H | NIQA |
|--------------------|--------------------|---------|-------|-------|------|
| FLPMF (b)          |                    | 7.298064| 0.016009| 0.016690 | 0.576072 |
| FLSM (c)           |                    | 6.011776| 0.080310| 0.019616 | 12.019138 |
| FLCM(d)            |                    | 4.873905| 0.137686| 0.042358 | 12.019138 |
| HE (e)             |                    | 4.982942| 0.150916| 0.076110 | 198.5050 |
| MSR (f)            |                    | 5.948462| 0.052666| 0.038869 | 3.992380 |

(a) [Image of Figure 3a] (b) [Image of Figure 3b]
Fig. 4. Image with its histogram (a) Original image, (b) Enhanced image of FLPMF, (c) Enhanced image of FZSM, (d) Enhanced image of FZCM, (e) Enhanced image of HE and (f) Enhanced image of MSR.

**TABLE (2):** QUANTITATIVE CRITERIA TO COMPARE METHODS THAT USED IN FIGURE 4.

| Enhancement Method | Quality Assessment |
|--------------------|---------------------|
|                    | Entropy | MSE-S | MSE-H | NIQA   |
| **FLPMF (b)**      | 7.210503 | 1.191608 | 0.010228 | 0.014154 |
| **FLSM (c)**       | 6.367064 | 18.553513 | 0.011986 | 0.090235 |
| **FLCM (d)**       | 5.535547 | 18.553513 | 0.015760 | 0.184531 |
| **HE (e)**         | 6.347079 | 165.0946  | 0.024821 | 0.118721 |
| **MSR (f)**        | 5.961692 | 18.1608  | 0.099630 | 0.040747 |
Fig. 5. Image with its histogram (a) Original image, (b) Enhanced image of FLPMF, (c) Enhanced image of FZSM, (d) Enhanced image of FZCM, (e) Enhanced image of HE and (f) Enhanced image of MSR.

| Enhancement Method | Quality Assessment |
|--------------------|--------------------|
|                    | Entropy  | MSE-S   | MSE-H   | NIOA    |
| FLPMF (b)          | 7.586565 | 1.996946 | 0.038100 | 0.020413 |
| FLSM (c)           | 6.952618 | 35.7801  | 0.051255 | 0.077928 |
| FLCM (d)           | 6.388943 | 35.7801  | 0.059842 | 0.092553 |
| HE (e)             | 6.637885 | 115.654  | 0.078971 | 0.043049 |
| MSR (f)            | 5.984124 | 22.0194  | 0.062336 | 0.017992 |
Fig. 6. Image with its histogram (a) Original image, (b) Enhanced image of FLPMF, (c) Enhanced image of FZSM, (d) Enhanced image of FZCM, (e) Enhanced image of HE and (f) Enhanced image of MSR.

Table 4: Quantitative criteria to compare methods that used in Figure 6.

| Enhancement Method | Quality Assessment |
|--------------------|--------------------|
|                    | Entropy | MSE-S | MSE-H | NIQA   |
| FLPMF (b)          | 0.660938| 0.0265929| 0.020649| 5.094067 |
| FLSM (c)           | 4.225009| 0.022023 | 0.105328| 6.066971 |
| FLCM(d)            | 4.225009| 0.026781 | 0.199040| 5.113748 |
| HE (e)             | 119.6689| 0.104392 | 0.089407| 6.154708 |
| MSR (f)            | 3.670349| 0.1139316| 0.093100| 5.759560 |

Objective assessment is often used to explain some necessary characteristics of the image. Therefore, the Entropy method measurement used to evaluate the improvement of detail in the image, MSES, MSEH and NIQE. In Fig. 3b-6b, the entropy is good for the image as shown in the tables (1-4). FLPMF has the highest value of entropy, this shows that the optimization is good. While other methods have smaller entropy values than the proposed method. The objective assessment includes two criterions MSE for saturation and MSE for hue. This assessment relies on the minimal measure value; this means that the results are good. Tables (1-4) corresponds to Fig. 3-6 and it has a clear view of the comparison for all methods used within this study.

5. Conclusions

All these tested images have low contrast and unbalanced lighting. The introduced algorithm beat all the methods by means of improve the lighting and preserve its details of the tested images. These 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 have been called 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 of the value, the better of entropy). As for the MSES, MSEH, and NIQE on the contrary, the smaller the values, the better. So the introduced algorithm beat all the traditional methods by means of improve the lighting and preserve its details and colors of the tested images.

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