LOW LIGHTNESS ENHANCEMENT USING NONLINEAR FILTER BASED ON POWER FUNCTION

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ABSTRACT

In fact, optical imaging systems produce images that demand to enhance low contrast, poor illumination, and other reasons. Thus, it is essential that those images pass through an improvement stage before testing them by specialists in many different applicative fields. Therefore, this research aims at improving the low lightness by a Nonlinear Filter Power Function (NFPF) algorithm. NFPF is applied to enhance the illumination of color images; it consists of three steps sequential: intensity enhancement, contrast enhancement, and color restoration of RGB channels. The interest of the proposed enhancement method has been evaluated depending on three criteria, namely: entropy, Normalize Mean Squared Error for Hue (NMSEH) and Normalize Mean Squared Error for Saturation (NMSES). The suggested algorithm (NFPF) was compared with four previous algorithms such as a Parallel Nonlinear Adaptive Enhancement (PNAE), New Nonlinear Adaptive Enhancement (NNAE), Multi-Scale Retinex with Color Restoration (MSRCR), and Histogram Equalization (HE). Qualitative results show that the proposed algorithm (NFPF) has outperformed other algorithms accordance to subjective and objective assessment.

Keywords: *Image Enhancement, Adaptation Power Function, Histogram Equalization, Intensity Enhancement.*

1. INTRODUCTION

The study of image enhancement to improve visual quality has gained increasing attention and become an active area in image and video processing [1]. The color images obtained by image acquisition devices like digital camera usually suffer from certain defects, such as low or high intensity with poor contrast and noises, and these defects result in poor visual quality. The principle objective of image enhancement is to process an image so that the result is more suitable than the original image for specific applications. Up to now, image enhancement has been applied to varied areas of science and engineering, such as atmospheric sciences, underwater environment, astrophotography, biomedicine, computer vision, etc. [2, 3]. Many image enhancement techniques have been proposed to improve the quality of degraded images captured in varying circumstances like Retinex-based methods [4] and the (NPNAE) algorithm [5].

Histogram Equalization (HE) is simple but widely-used for image enhancement. Since conventional HE algorithms may result in over enhancement, many algorithms with restrictions, such as brightness preservation [6], and contrast limitation [7], have been proposed. Brightness preservation is useful in the applications that need to preserve the intensity. However, for non-uniform illumination images, brightness preservation is disadvantageous to detail enhancement in the areas of inappropriate intensity, such as the dark areas. Contrast limited algorithms restrain over-enhancement by redistributing the histogram in such a way that its height does not go beyond the clip limit. But, it is not easy to fix the clip limit for the images of seriously non-uniform illumination, in which the histograms of different areas are quite different. Falsification of colors is the defect of this algorithm.

Retinex [4] Theory assumes that the sensations of color have a strong correlation with reflectance, and the amount of visible light reaching observers depends on the product of reflectance and illumination [7]. Most Retinex-based algorithms extract the reflectance as the enhanced result by removing the illumination, and therefore they can enhance the details obviously. But it is impossible to exactly remove the illumination for the scenes of unsmooth depth. Some center/surround algorithms take the local convolution of the lightness instead of the illumination without considering the limit of the reflectance. In fact, the reflectance should be within [0-1], which means the surface cannot reflect more light than that it receives. Moreover, it is unreasonable to simply remove the illumination which is essential to represent the ambience [8] the defects of this algorithm is the halo effect [9].

Recently, some of Nonlinear Adaptive enhancement algorithms are suggested such as: New Nonlinear Adaptive Enhancement (NNAE) algorithm [5] which bases on an adaptive intensity adjustment with local contrast enhancement, and Parallel Nonlinear Adaptive Enhancement (PNAE) algorithm [12] which depends on adaptive intensity adjustment based on the local neighborhood. (NNAE and PNAE) algorithms are applied to enhance images that have low illumination issue. In general, these algorithms are may be suitable and goodly for low illumination; but, not enough for non-uniform illumination.

In this paper, a lightness enhancement algorithm is proposed for both of low illumination and non-uniform illumination images. In general, we address three main issues accompanying with color images, namely, the intensity effect, poor contrast, and darkness of colors.

2. PROPOSED ALGORITHM

A Nonlinear Filter Power Function (NFPF) algorithm is uses to improve the optical quality of digital images captured under extremely low or non-uniform lighting conditions. Our algorithm consists of three important parts that lead to better enhancement results: (i) Adaptive Intensity Enhancement, (ii) Contrast Enhancement, and (iii) Color Restoration. The diagram of the proposed algorithm is given in figure (1).

2.1 Adaptive Intensity Enhancement

The first point of this algorithm is being made up of three sub parts: (a) intensity estimation, (b) adaptive power function, and (c) median filter.

2.1.1 Intensity Estimation (IE)

The transformation of color image from basic RGB color space to YIQ color space is done through the following formula:

$$I = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.270 & -0.322 \\ 0.211 & -0.253 & 0.312 \end{bmatrix} \quad (1)$$

The image intensity *I (x, y)* can be formulated as a product:

$$I(x,y) = L(x,y)R(x,y) \quad (2)$$

Where: *R (x, y)* is the reflectance and *L (x, y)* is the illumination at each position (x, y).

The luminance *L* is assumed to be contained in the low frequency component of the image while the reflectance *R*, mainly represents the high frequency components of the image. For estimation of illumination, the result of Gaussian low-pass filter applied on the intensity image is used. In spatial domain, this process is a 2D discrete convolution with a Gaussian kernel which can be expressed as:

$$I_C(x,y) = L(x,y) = I(x,y) \otimes F(x,y,C) \quad (3)$$

Where *Ic*: is convolution image, and (F) is the Gaussian convolution function [10].

2.1.2 Adaptive Power Function (APF)

Power-law transformations are used in general objective contrast dealing. In the current paper, a power function is used to adjust an illumination curve. As shown in figure (2), where illumination was enhanced according equation (4):

$$I_{out} = \alpha + \beta[I_c\,(x,y)]^{\gamma} \quad (4)$$

Where $\alpha = 0.0062$, $\beta = 0.9367$, and $\gamma = 0.5424$ are a numerical stability factors.

2.1.3 Median Filter

The median filter technique is a known statistic filter and used widely because of its effective noise suppression capability and high computational efficiency while preserving edges, which replaces the value of a pixel by the median of the gray levels in neighborhood of that pixel [11]. In other words,

$$\hat{I}_{out}\,(x,y) = Median\,\{\,(I_{out}(x,y)\} \quad (5)$$

2.2 Contrast Enhancement:

The second point of the proposed algorithm is done by Center-surround contrast enhancement using:

$$R = \hat{I}_{out} \otimes R_i \quad (6)$$

$$R_i = W_i\,S_i \quad (7)$$

$$S_i = 255\,(\hat{I}_{out})^{F_i} \quad (8)$$

$$F_i = \frac{R_i}{\hat{I}_{out}} \quad (9)$$

Where: i = 1, 2, 3; which represents the channels of colors (red, green, blue).
(W_i): is the weight factor for each constant enhancement; (w_1=w_2=w_3=1/3).

2.3 Color Restoration

In this stage, a linear color restoration process is applied, which is based on the chromatic information of the original image. Where, it converts the enhanced intensity image to RGB color image. The restored colors image (r_e, g_e, b_e) can be obtained through equations (10 and 11):

$$C_e(i,j,k) = C(i,j,k)R_K \quad (10)$$

Where: K = 1, 2, 3; which represents the channels of color (red, green, blue).

$$r_e = \frac{R}{I}r, \quad b_e = \frac{R}{I}b, \quad g_e = \frac{R}{I}g \quad (11)$$

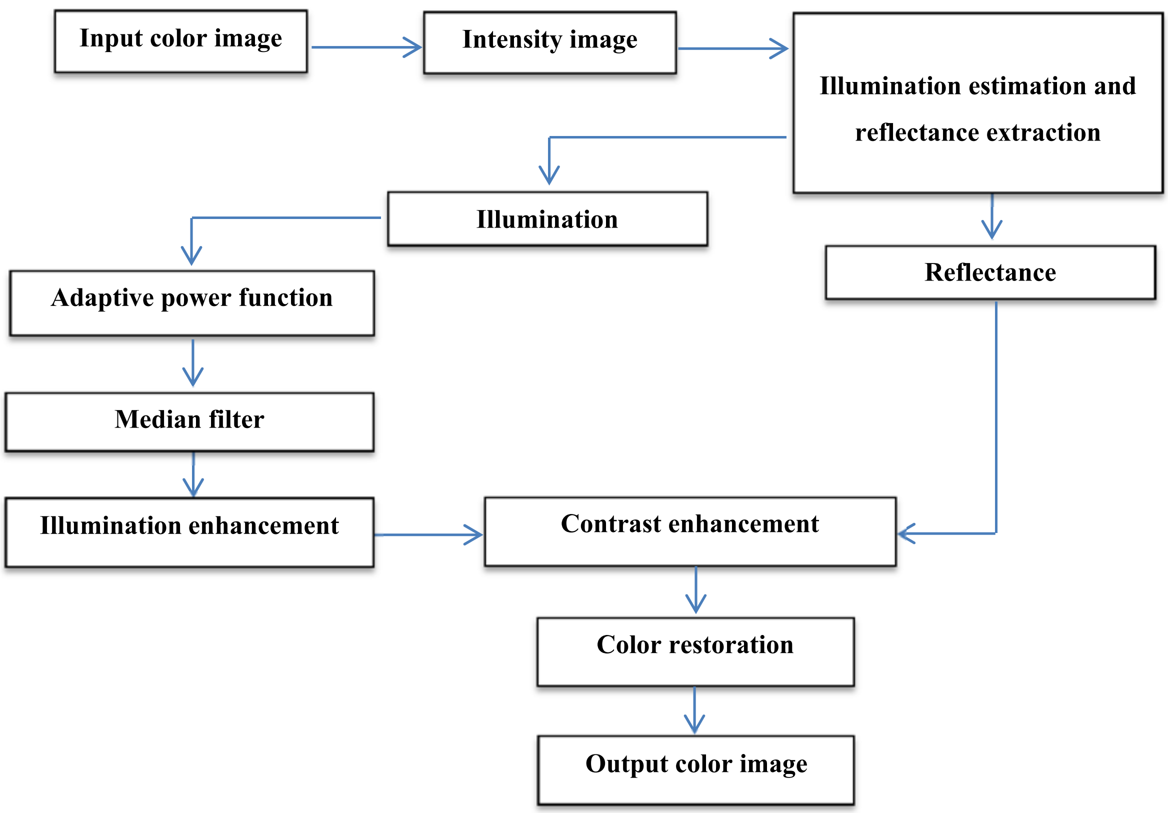


Figure 1: The diagram of NFPF algorithm.

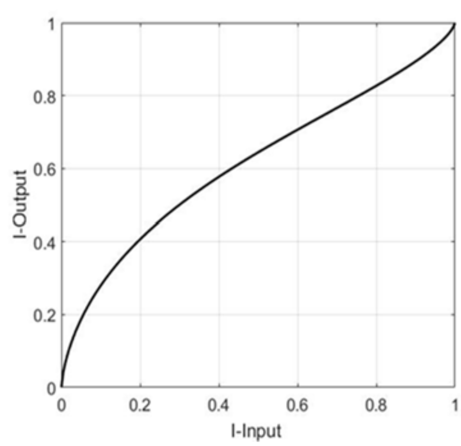


Figure 2: Relationship between input lightness versus output lightness by adaptive power function.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Steps of (NFPF) algorithm

a. Input color image *I (x, y)*.
b. Estimating the illumination of image I(x, y).
c. Normalizing the component of illumination $I_n(x,y) = I_c(x,y) / 255$.
d. Applying the power function through equation (4).
e. Appling median filter on (I_{out}).
f. Computing reflectance image from equation (6).

The PNAE [12] is a method for low lightness image enhancement consists of three stages: (i) converting (RGB) color image to an intensity image, (ii) then modifying intensity with contrast enhancement based on neighborhood locality, and then (iii) color restoration process which is depending on the chromatic information of the original image. The NNAE [5] method, is an improved method for PNAE. Where, the intensity mapping function is approximated by the Second Order Taylor Series (SOTS) expansion instead of the First Order Taylor Series (FOTS) expansion that used in PANE.

3. QUALITY ASSESSMENT

This research employs non- chromatic compounds (V) and when calculating quality in chromatic compounds like (H) and (S) [8].

3.1 Entropy

It is one of the common quality measures. It is used to measure the quality of image. Images which have maximum entropy have the better quality of the image. We use the visual (V) element, which is one of the color space (HSV) components.

$$Ent\ (V) = -\sum_{v=0}^{255} p(v) \log p(v) \qquad (12)$$

Where: (*Ent*) represents an entropy of the image, (*v*) is the total number of gray level, and p (*v*) is the probability density function at intensity level *v*.

3.2 Normalize Mean Squared Error

In this part, we calculate the MSEs for: hue (H) and saturation (S) using following equations:

$$\mathrm{NMSEH} = \frac{1}{\mathrm{M} \times \mathrm{N}} \sum_{x=1}^{M} \sum_{y=1}^{N} ((\mathrm{H_E}(x,y) - \mathrm{H_o}(x,y))^2 \quad (13)$$

$$\mathrm{NMSES} = \frac{1}{\mathrm{M} \times \mathrm{N}} \sum_{x=1}^{M} \sum_{y=1}^{N} ((\mathrm{S_E}(x,y) - \mathrm{S_o}(x,y))^2 \quad (14)$$

Where: (H_o and S_o) represent hue and saturation for the original image with size (N×M), and (H_E and S_E) represent the hue and saturation for an enhanced image respectively.

4. RESULTS AND DISCUSSIONS

In this paper, the database consists of six images, with type of JPEG format, and size of 360×236, and 283×432 pixels. It's taken from previous studies. All images are low or high intensity and poor contrast, (figures 3a-8a) in the Test Images Database of Computer Vision Group [13] aimed to test the feasibility of proposed method (NFPF).

This paper proposes an adaptive algorithm of intensity modify by power function and local contrast enhancement based on center-surround for color images enhancement that have low lightness. The proposed NFPE algorithm, inspired by the algorithms PNAE and NNAE is able to simultaneously enhance the image intensity and local contrast with better visual effects. The performance of the proposed NFPE algorithm has been compared in term of both visually and numerically with four previous methods. Experimental results show that the NFPE algorithm outperforms those four in terms of computational efficiency, also provides better visual representation in numeral comparisons.

The proposed method is compared to four other methods, which are: MSRCR [4], NNAE [5], HE [6], and PNAE [12]. MATLAB software program was used to simulate the proposed method which based on association of different methods together. This procedure leads to get some of results that help us to find the advantages of these methods and techniques on poor lightness images. In this work, the algorithms from subjective assessment aspect is tested, and then perform objective assessment, using the entropy [8], Normalize Means Squared Error for hue NMSEH and saturation NMSES. The quantitative results for the selected images are illustrated in the tables 1–3.

5. IMAGE QUALITY ASSESSMENT

Quality of image is always an outcome of human sensation. HVS is the final decisions about quality based on their own visual preferences that, naturally, are not only affected by the psychophysical aspects of the observer, but also the fidelity of the image and the observation situation.

Journal of Theoretical and Applied Information Technology
15th January 2019. Vol.96. No 1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The quality of image can be broadly classified into two categories: subjective and objective.

5.1 Subjective Assessment

This kind depends on human visual system. Therefore, some defects are seen in all methods of enhancement, such as, the images that are tested by MSRCR algorithm have halo effect as shown in figures (3(f)-8(f)), and the images that are tested by HE method; it colors have become false as shown in figures (3(d)-8(d)), while the images that enhanced by PNAE method; have slight false color as shown in figures (3(e)-8(e)).

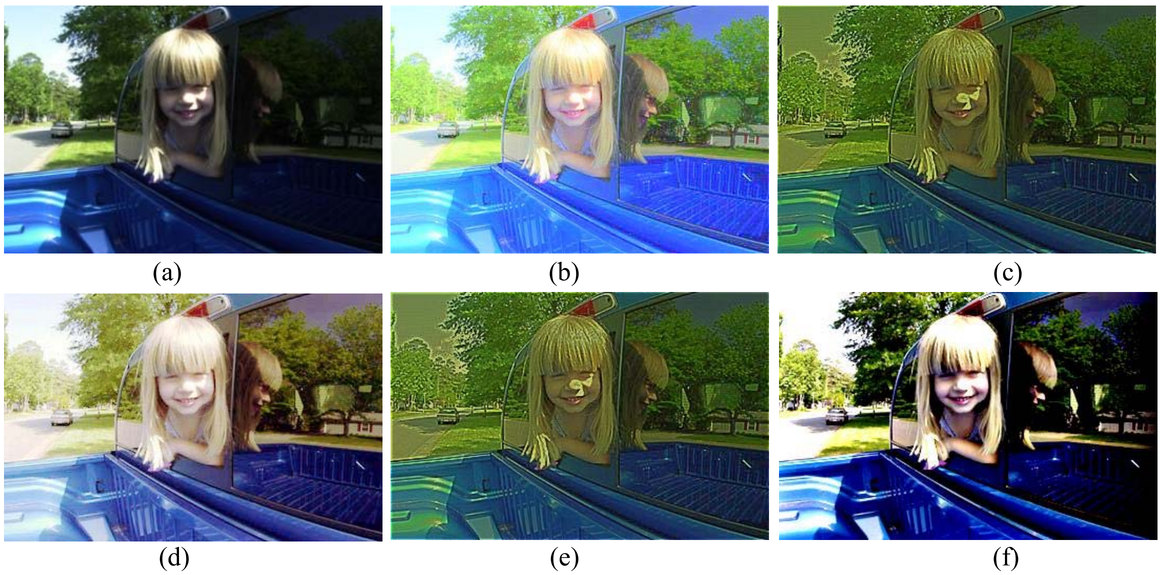


Figure 3: Results for image Baby girl in a car. (a) Original image, (b) Enhanced image of NFPF, (c) Enhanced image of NNAE, (d) Enhanced image of HE, (e) Enhanced image of PNAE, and (f) Enhanced image of MSRCR.

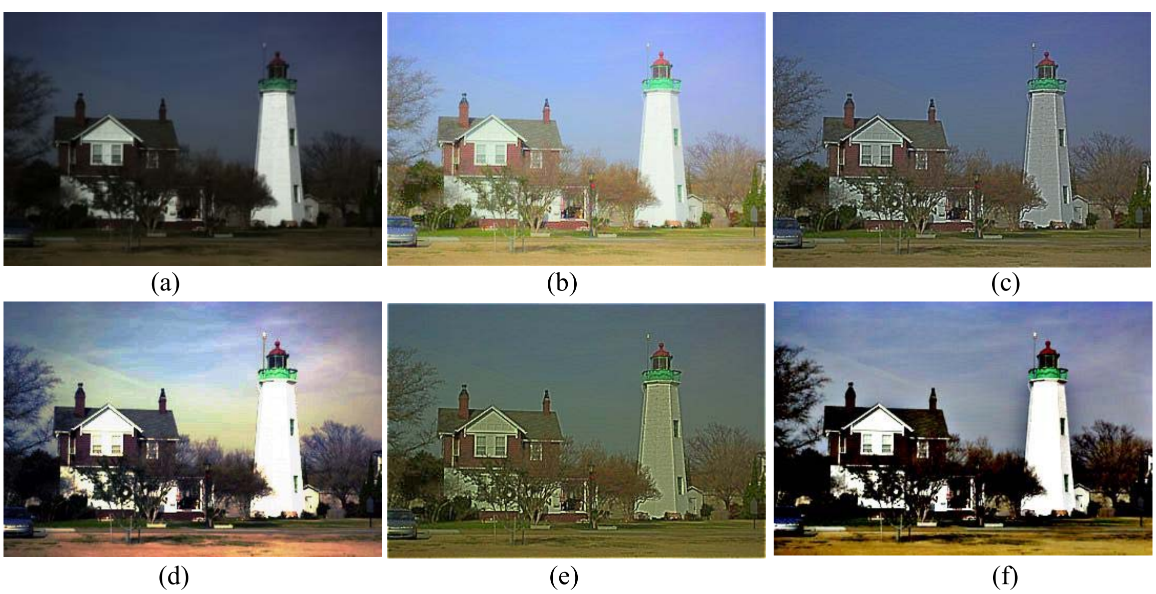


Figure 4: Results for image Minaret. (a) Original image, (b) Enhanced image of NFPF, (c) Enhanced image of NNAE, (d) Enhanced image of HE, (e) Enhanced image of PNAE, and (f) Enhanced image of MSRCR.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

(a) (b) (c) (d) (e) (f)

Figure 5: Results for image Family. (a) Original image, (b) Enhanced image of NFPF, (c) Enhanced image of NNAE, (d) Enhanced image of HE, (e) Enhanced image of PNAE, and (f) Enhanced image of MSRCR.

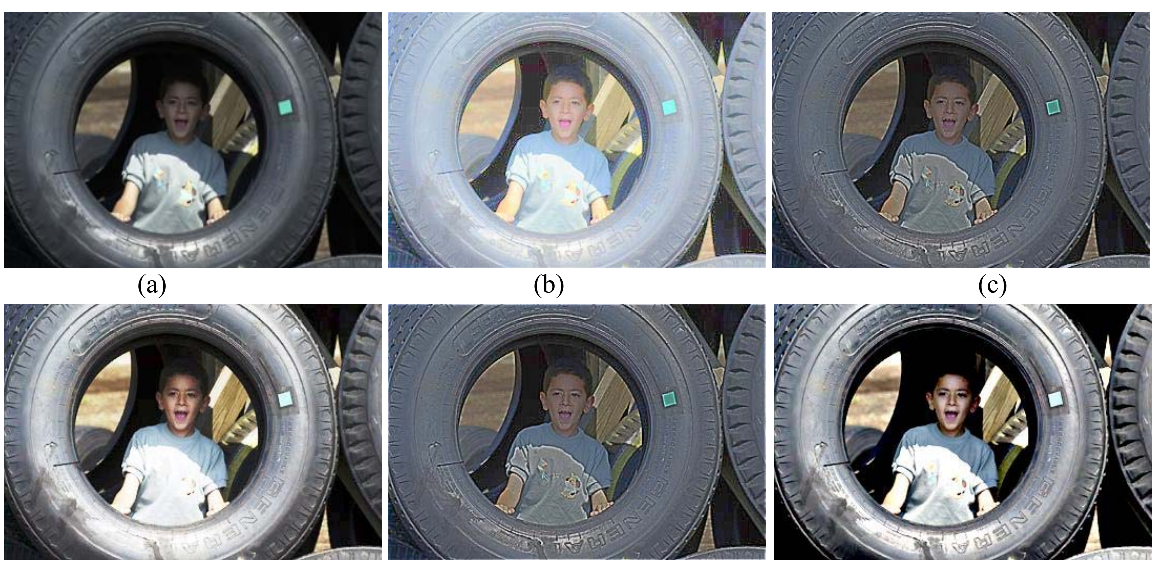
In connection with the proposed criteria NMSEH and NMSES, it is known that when adjusting the intensity of any image to improve a non-uniform or darkness illumination; results in deformation of the colors (changing in hue and saturation components). So in the present research, a novel evaluation criterion is used to detect the amount of change in these two components. As defined in [14, and 15], The MSE is a measure of the quality assessment, and values closer to zero are better (i.e., the lowest value of MSE for two estimators indicate to optimum quality and vice versa).

5.2 Objective Assessment

As subjective assessment depends on human visual system, it is hard to find an objective measure that is in accordance with the subjective assessment, because the objective assessment is dealing always with information and characteristics of images [16].

So, the resultant images are evaluated by quantitative measure called entropy [8]. The resultant images are displayed in figures (3-8), the numerical values of objective assessment that represented entropy are showed in table (1), and the subjective assessment that represented by NMSEH and NMSES are demonstrated in the tables (2 and 3) respectively. In all figures (3b-8b), one can note, it is visually apparent that the proposed method NFPF is the best quality.

In terms of quality assessment of its substantive and subjective branches, the following paragraphs are focuses on discussion and a comparison of the results reached in this research in tables (1-3). Where, the red value indicates exceptional value, while the bold values indicate the best value in the comparison.



(a) (b) (c)

(d) (e) (f)

Figure 6: Results for image Tire. (a) Original image, (b) Enhanced image of NFPF, (c) Enhanced image of NNAE, (d) Enhanced image of HE, (e) Enhanced image of PNAE, and (f) Enhanced image of MSRCR.

(a) (b) (c) (d) (e) (f)

Figure 7: Results for image Baby girl standing. (a) Original image, (b) Enhanced image of NFPF, (c) Enhanced image of NNAE, (d) Enhanced image of HE, (e) Enhanced image of PNAE, and (f) Enhanced image of MSRCR.

(a) (b) (c) (d) (e) (f)

Figure 8: Results for image Boy. (a) Original image, (b) Enhanced image of NFPF, (c) Enhanced image of NNAE, (d) Enhanced image of HE, (e) Enhanced image of PNAE, and (f) Enhanced image of MSRCR.

Table 1 illustrates an entropy values for set of images that are presented above in figures ((3)-(8)). As defined in [17], separated entropy is a statistical measure of random event, and higher value of entropy usually point out to wider details. From Table 1, one can see that the entropy values of our method are optimized, and superior to the other four algorithms. Where, PNAE and MSRCR algorithms have a lowest entropy values among the four algorithms, according to its performance in enhancing characteristics of the image.

Table 2 demonstrates the quantitative criterion of hue component descriptor, which expression about the quality of colors improvement of the enhanced images after improving their illumination. From Table 2, we can note that the NMSEH values for our algorithm lowest than values of other previous algorithms. This is really important, because that indicates a slight change in Hue component after applied Adaptive Power Function APF (i.e. good approach in adjusting of illumination). PNAE has a higher NMSEH values among the four algorithms, according to Hue component which distorts the image.

Table 3 demonstrates the quantitative criterion of saturation component descriptor, where it describes the intensity (purity) of that hue. Note from Table 3, as well as the NMSES values for our algorithm are lowest than of other algorithms previous. This mean that the amount of error in the information of color is minimal after applied Adaptive Power Function APF. PNAE and MSRCR have a higher NMSES values among the four algorithms, according to Saturation component which distorts the image. Except for one case for HE algorithm, although the value of (saturation) high, but in other hand shows its intensity also high as shown in figure (8-d).

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table1: Quantitative assessment (Entropy), and comparison among proposed method and other previous publications.

Images \ Methods	NNAE	HE	PNAE	MSRCR	Proposed
Baby girl in a car	7.274373	7.238489	4.982942	5.948463	**7.686629**
Minaret	6.880656	7.144907	6.34708	5.961693	**7.514308**
Family	6.987732	6.950831	4.281454	5.57797	**7.116621**
Tire	7.083101	7.03466	6.637885	5.984124	**7.572121**
Baby girl standing	7.098088	7.092514	6.319316	5.971654	**7.320692**
Boy	6.608577	6.567375	6.219689	5.597017	**6.634399**

Table2: Quantitative assessment (NMSEH), and comparison among proposed method and other previous publications.

Images \ Methods	NNAE	HE	PNAE	MSRCR	Proposed
Baby girl in a car	0.067001	0.091276	0.150916	0.052666	**0.000213**
Minaret	0.028464	0.000555	0.118721	0.040748	**7.56E-05**
Family	0.002732	0.000684	0.118202	0.063911	**0.000216**
Tire	0.000208	0.000289	0.043049	0.017993	**4.11E-05**
Baby girl standing	0.000231	0.000195	0.159503	0.102196	**5.39E-05**
Boy	0.023469	0.019468	0.135643	0.05306	**9.38E-05**

Table3: Quantitative assessment (NMSES), and comparison among proposed method and other previous publications.

Images \ Methods	NNAE	HE	PNAE	MSRCR	Proposed
Baby girl in a car	0.023931	0.00431	0.024821	0.09963	**1.24E-05**
Minaret	0.031189	0.033997	0.07611	0.03887	**7.19E-05**
Family	0.04552	0.028951	0.183097	0.085229	**7.63E-05**
Tire	0.02613	0.020529	0.078971	0.062336	**2.85E-05**
Baby girl standing	0.001352	0.001465	0.074269	0.111953	**7.57E-06**
Boy	0.107639	0.117346	0.098459	0.059608	**0.008002**

In summary, the power - law transformation that is used in the process of adaptive lighting is a very simple and efficient way; it was applied to adjust the lightness and brightness of the colored image.

The findings of this study indicate that the approach cannot enhanced the illumination only, but it also conserves its characteristics, the approach is suitable to correct the color false by correcting the illumination for the three color channels (R, G, B) respectively.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

This project produced high quality images with high contrast level and gives the natural colors. The results of this project can be utilized in many applications especially in medical images, underwater, and night vision.

6. CONCLUSION

Optical devices always produced images that demand to enhance, due to low contrast, and low or high illumination. Thus, it is essential that those images pass through the improvement stage before testing them by specialists in many different applicative fields such as medical imaging system, observation, underwater, and other fields.

This paper proposes a novel algorithm to enhance the colored images that have low lightness through applying Nonlinear Filter Power Function NFPF. NFPF algorithm is consists of three main parts: adaptive intensity enhancement, contrast enhancement, and color restoration. The importance of this algorithm does not lie only in enhancing lightness of the image, but also preserves its colors and details.

In dealing with quality criteria, two categories have been adopted, namely: objective assessment and subjective assessment. Concerning the objective assessment which depends on characteristics of image such as entropy (*Ent*), while, the second depends on system of human sensation HVS. So, the MSEs are calculated or hue NMSEH and saturation NMSES.

According to the quality assessment, the results show that our algorithm has highly accuracy in processing in two evaluations (subjective and objective). A comparison is made among the proposed method and four other methods are: NNAE, PNAE, MSRCR and HE.

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