A Color Image Enhancement Method Based on Ensemble Empirical Mode Decomposition and Genetic Algorithm

Somayeh Bakhtiari
Student Member, IEEE
Somayeh.bakhtiari@utsa.edu

Sos Agaian and Mo Jamshidi
Senior member of IEEE and Fellow, IEEE
sos.agaian@utsa.edu, moj@wacong.org

***Abstract*—In this paper, we introduce a new method for enhancement of the color images. The proposed approach utilizes Ensemble Empirical Mode Decomposition (EEMD) and Genetic Algorithm (GA). The algorithm is tested on the underwater images and the underexposed scenes. For the dark images, a nonlinear transform is first performed on the original image as a preliminary illumination correction. For underwater images, the mean of each RGB channels is initially corrected based on a GA-oriented technique. After the preprocessing steps, an EEMD based method is applied on the luminance channel of the resulting image to further correct the brightness of the image. The Genetic Algorithm enables the presented method to set the required parameters automatically. The experimental results demonstrate the effectiveness of the algorithm in visual enhancement of the color images.**

Keywords- Color Image Enhancement; Underwate Image; EMD; EEMD; Genetic Algorithm.

I. INTRODUCTION

Images with inadequate or non-uniform brightness do not expose the necessary details. This can make the information extraction tasks very difficult. Many image enhancement methods have been developed to alleviate the quality of such images. The illumination correction is an essential preprocessing step in image enhancement methods which deal with the images lacking sufficient or uniform brightness. A number of well-known existing methods developed for illumination enhancement include gamma correction, histogram equalization and homomorphic filtering. To improve the quality of the color images, various color spaces can be adopted. Asmare et al. [1] investigated several color spaces and evaluated their performance in color image enhancement. They conclude that HIS/HSV performs the best among all for such purposes. A method is introduced by Wu et al. [2] based on tone mapping technique to adjust brightness of the image. Tone mapping maps one set of colors to another, often to approximate the appearance of high dynamic range images in a medium that has a more limited dynamic range [3]. They have defined a new color space which introduces new RGB values. The altered color signals, then, are combined with the modified illumination to construct the final enhanced image. Tan et al. [4] estimate the value of the light chromaticity and utilize the inverse intensity chromaticity space to enhance the visibility in hazy or foggy scenes. This method operates based on a linear correlation between the light chromaticity and image chromaticity. To increase contrast in the dark areas of a scene, Zhao et al. [5] present an algorithm which adaptively maps a luminance value into a value based on a piecewise linear mapping curve. Their technique combines global and local enhancements which are based on a modified histogram equalization scheme. The local enhancement is performed on non-overlapped blocks only when required. Ding et al. [6] introduce a new color image enhancement algorithm based on human visual system adaptive filter. The method consists of three steps: obtaining the luminance image and background image, adaptive adjustment and color restoration. Unlike most of the other color image enhancement techniques, their approach exploits color information, as well. Meylan et al. [7] propose a solution for enhancement of the high dynamic range images based on the Retinex model. The Retinex determines the perceived color given spatial relationships of the captured signals. In their approach a single filter is applied to the luminance channel. Pei et al. [8] present a hybrid method, including brightness and color contrast enhancements. Their technique deploys the chromaticity domain of the color space, and the Y component of the XYZ color space. The chromatic enhancement consists of saturation and de-saturation operations in the chromaticity diagram. In order to enhance brightness in the Y component, adaptive histogram equalization is applied. Patel et al. [9] use a nonlinear sine transfer function with an adaptive parameter for color image enhancement purpose. The use of the image dependent control parameter increases its flexibility in enhancement of the dark regions and compression of the overexposed regions in an image.

The Empirical Mode Decomposition (EMD) is another technique effectively adopted for image enhancement purpose. A number of EMD-based methods have been developed for enhancement of the medical images [10][11], underwater images [12], hazy images [13] and other low quality images. The problem with these methods is that the weights and other parameters in the algorithm are manually set which may not be the optimal ones; while, by optimizing the parameters they can approach the near optimal solution. The Genetic Algorithm is an approach which has been employed to solve complex optimization problems using simulated genetic evolution. It can be significantly helpful when the search space is very broad, the size of data to e processed is huge and other optimization techniques may fail to extract the optimal solution. The GAs produce a decent solution efficiently, by iteratively performing selection and reproduction to a population of individuals representing solutions of the problem [14]. In [15] a contrast enhancement method is proposed based on genetic algorithm. The presented algorithm of [16], optimizes the parameters of a modified versions of a local enhancement method similar to statistical scaling method. To enhance the contrast of a gray image a solution is proposed in [17] based on the GA in which, the fitness of an individual is estimated by evaluating the intensity of spatial edges of the image. A lookup- table (LUT) is used to define the relationship between input gray levels and output gray levels. In [18], an enhancement method is implemented using discrete stationary wavelet transform (SWT), generalized cross-validation (GCV), genetic algorithm (GA), and non-linear gain operator, an efficient de-noising and enhancement algorithm for typhoon cloud image. The old documents are enhanced and restored in [19] via a GA-based technique. The fitness function is defined to be number of edges with only 1 pixel.

This study proposes a new enhancement algorithm for the underexposed images and the underwater images using a nonlinear transform, EEMD and GA. The HSV color space is selected for brightness modification purpose, since it has shown a higher effectiveness in the applications understudy.

The paper is organized as follows: Section 2 presents some background information on traditional EMD and EEMD algorithm. Section 3 introduces the proposed approach. Section 4 presents the simulation results. In section 5 some concluding comments are presented.

II. BACKGROUND

HSV/HSI (Hue Saturation Lightness Value/ Intensity): This is a non-linear transform of the RGB color space. Perfect separation of the luminance component from the chrominance information makes it advantageous in image processing. It is also extremely intuitive. However, it is non linear and device dependent. It is widely used in the field of color vision [20].

Empirical Mode Decomposition (EMD): EMD is a signal decomposition technique, first proposed by Huang et al. [21] to analyze some nonlinear and non-stationary processes. The principle of EMD is decomposing a signal into a set of functions called Intrinsic Mode Functions (IMFs) and a residue. The IMFs are characterized by having the same number of zero crossings and extrema and, having envelopes symmetric with respect to the local mean. This algorithm localizes maxima and minima of the signal and is an adaptive local decomposition method. A strength point of EMD is that the basis functions are derived from the signal itself [22]. By adding the IMFs and the residue we can reconstruct the original signal without any loss. The decomposition is carried out using the sifting process as follows [22][23]:

1. Find all the local minima and maxima in the image,
2. Interpolate the local maxima to form the upper surface denoted by S_{max}
3. Interpolate the local minima to construct the lower surface specified by S_{min},
4. Estimate the mean of the upper and the lower envelope :

$$m(x,y) = \frac{1}{2}(S_{max}(x,y) + S_{min}(x,y))$$

where, (x,y) indicates the spatial location.

5. Set h(x, y) as the difference of image I(x, y) and m(x, y):

$$h(x,y) = I(x,y) - m(x,y)$$

Repeat above procedure k times until h(x, y) is an IMF.

$$h_{1k} = h_{1(k-1)}(x,y) - m_{1k}(x,y)$$

The first IMF is denoted by imf_1 (x, y) and

$$imf_1(x,y) = h_{1k}(x,y)$$

Subtract imf_1(x, y) from the original image

$$R_1(x,y) = I(x,y) - imf_1(x,y)$$

Treat R_1(x, y) as a new signal and repeat the above procedure n times. The iteration is as follows:

$$R_n(x,y) = R_{n-1}(x,y) - imf_n(x,y)$$

The ultimate expression is:

$$I(x,y) = \sum_{i=1}^{n} imf_i(x,y) + R_n(x,y)$$

where, I is the original image, imf_i is the i^{th} IMF, and R_n is the residue. The first IMF contains the finest details and the residue is the ultimate large scale trend.

Ensemble EMD (EEMD): The decomposition results by EMD suffer from mode mixing. Mode mixing happens when a single IMF consists of widely disparate scales, or a signal resides in several IMF components [21]. Wu et al. [2] introduced ensemble EMD (EEMD) to overcome mode mixing. EEMD iteratively decomposes the signal into its IMFs using the EMD technique. During each iteration, white noise of finite amplitude is added to the original signal. Ultimately, corresponding ensemble IMFs produced in each trial will be averaged and regarded as the IMFs of EEMD algorithm:

$$EEMDimf_i = \frac{1}{IterNum} \sum_{j=1}^{IterNum} imf_{ij}$$

where, $EEMDimf_i$ is the i^{th} IMF of EEMD, imf_{ij} is the i^{th} IMF in j^{th} iteration and IterNum is the number of iterations.

III. PROPOSED METHOD

In this section, a new solution is presented for enhancing the color images in sense of color and brightness. The algorithm is tested on several dark scenes and underwater images. The main idea is to modify the luminance channel of the image. To have a more satisfactory result, a preprocessing step is necessary before the main brightness adjustment step. For this purpose, we have proposed two approaches, one applied on the regular dark images and the other one employed for underwater images. For the dark images, the luminance channel is transformed using a nonlinear function to slightly balance the light in whole regions of the image. Since, in the underwater scenes, the blue and green colors are dominant, each channel of RGB should be adjusted to a desired mean value. To achieve this, each of the channels are increased or decreased by a constant estimated by GA method. Then, to enhance the illumination, the RGB color space is transformed into the HSV (Hue, Saturation, Value). For this particular application, HSV has shown to produce better results compared to the other color spaces such as YCbCr, which give the illumination as a separate channel.

$$V' = CV^{a}e^{-V^{b}}$$

where, V represents the luminance Value channel; V' is the transformed Value channel; C, a and b are real valued constants.

Fig. 1 and Fig. 2 show the role of a and b parameters in the transfer function, respectively. As depicted in Fig. 1, the smaller values of a will magnify the small pixel values more, compared to the larger values of a. As a result, the dark regions of the image will become brighter; while the lighter areas remain almost the same as before. Thus, in the images with nonuniform illumination the smaller values of a is applicable. On the other hand, in uniformly illuminated images the larger values of a is more feasible, particularly when the contrast enhancement is the goal. Fig. 2 illustrates that larger values of b are suitable for the images with regions of unequal brightness.

In the nonuniform illuminated images, these two parameters should not be chosen such that the small pixel values will be mapped to the much higher values. This limitation is posed in order to obtain an image with a natural look.

For the underwater images, the RGB values are modified as follows:

$$R' = M_1 + R$$
$$G' = M_2 + G$$
$$B' = M_3 + B$$

where, R, G and B are the original Red, Green and Blue values; R', G' and B' are the corresponding modified values; M_1, M_2, M_3 are constants with positive or negative value which are used to adjust the mean value of Red, Green and Blue channels to the desired levels. They are estimated using GA approach.

The illumination correction procedure is based on the following equation:

$$V'' = \frac{\beta_0 V'}{\sum_{i=1}^{n} \beta_i imf_i + \beta_{n+1} R_n} + \sum_{i=1}^{n} \gamma_i imf_i + \gamma_0 V'$$

where, V'' is the enhanced illumination; β_i and γ_i are constant approximated by a GA based method. The imf_i is the i^{th} IMF.

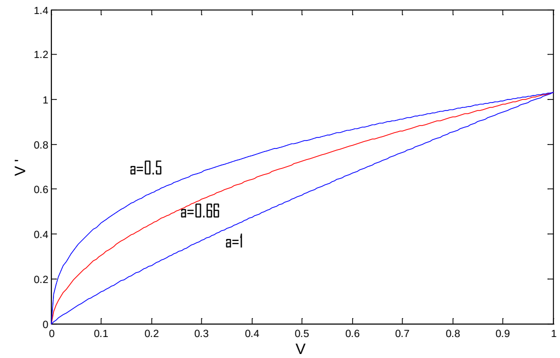


Figure 1. Role of ‘a’ in transfer function. V and V’ are the input and output luminance values, respectively.

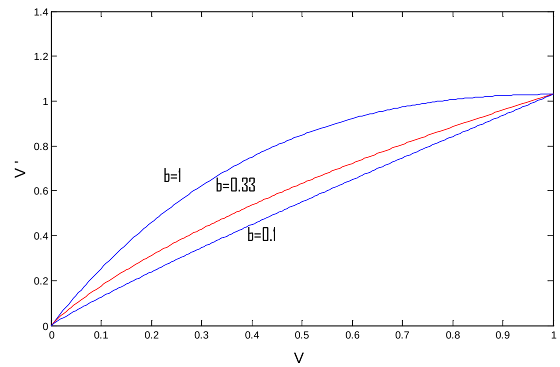


Figure 2. Role of ‘b’ in transfer function. V and V’ are the input and output luminance values, respectively

After this step, color space of the resulting image will be converted from HSV to RGB.

The block diagrams of the enhancement procedure for the underexposed and underwater images are presented in Fig. 3 (a) and (b), respectively.

To estimate the parameters used in the proposed algorithm, the Genetic Algorithm (GA) is adopted. Three operations, reproduction, crossover and mutation are performed in GA. In this study, the chromosome consists of an array of integer or floating point numbers, each indicating a parameter value. In the RGB modification algorithm the numbers are integer and in the illumination correction, the floating point numbers are generated. In crossover operation, a weighted sum of the two parents is produced as the offspring as:

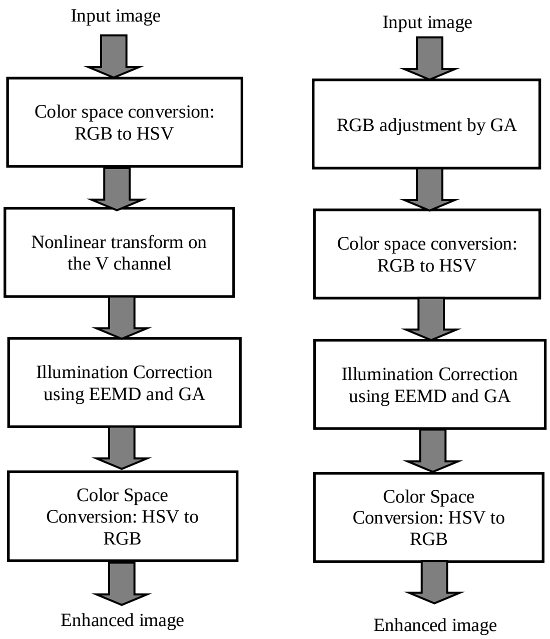
$$x_{child} = a x_{parent1} + (1-a) x_{parent2}$$

Where, a is a real valued constant between 0 and 1. The crossover probability is 0.75.

Mutation is carried out by adding or subtracting a mutation value from a randomly selected chromosome. The mutation probability is 0.025.

The GA parameters used in this study are listed in table 1.

The mutation value1 is used to approximate the parameters in illumination correction method, namely, β_i and γ_i. To estimate the offsets of RGB channels, M_1, M_2 and M_3, the mutation value2 is used.



(a) (b)

Figure 3. Block diagrams of the enhancement procedure (a) for the dark images (b) for underwater images

TABLE 1 GENETIC ALGORITHM PARAMETERS VALUES

Parameter	Value
Chromosome representation	Integer and floating point
population size	20
crossover probability	0.75
mutation probability	0.025
number of the generations	60
mutation value1	0.01
mutation value2	1
Fitness function	EME

The EME of the luminance is selected to be the fitness function [15]. It is called measure of enhancement, or measure of improvement and is defined as:

$$EME = \max_{\Phi \in \{\Phi\}} \chi\big(EME(\Phi)\big)$$
$$= \max_{\Phi \in \{\Phi\}} \Big(\frac{1}{k_1 k_2} \sum_{l=1}^{k_2} \sum_{k=1}^{k_1} 20\log \frac{I^{\omega}_{max;k,l}(\Phi)}{I^{\omega}_{min;k,l}(\Phi)}\Big)$$

where, $I^{\omega}_{max;k,l}(\Phi)$ and $I^{\omega}_{min;k,l}(\Phi)$ respectively are the minimum and maximum of the image $x(n,m)$ inside the block $\omega_{k,l}$ after processing the block by Φtransform based enhancement algorithm. The function χ is the sign function, $\chi(x) = x$, or $\chi(x) = -x$, depending on the method of enhancement under consideration [15].

The EME is used to measure the quality of the luminance value of the image after using the parameter values selected by GA.

IV. SIMULATIONS

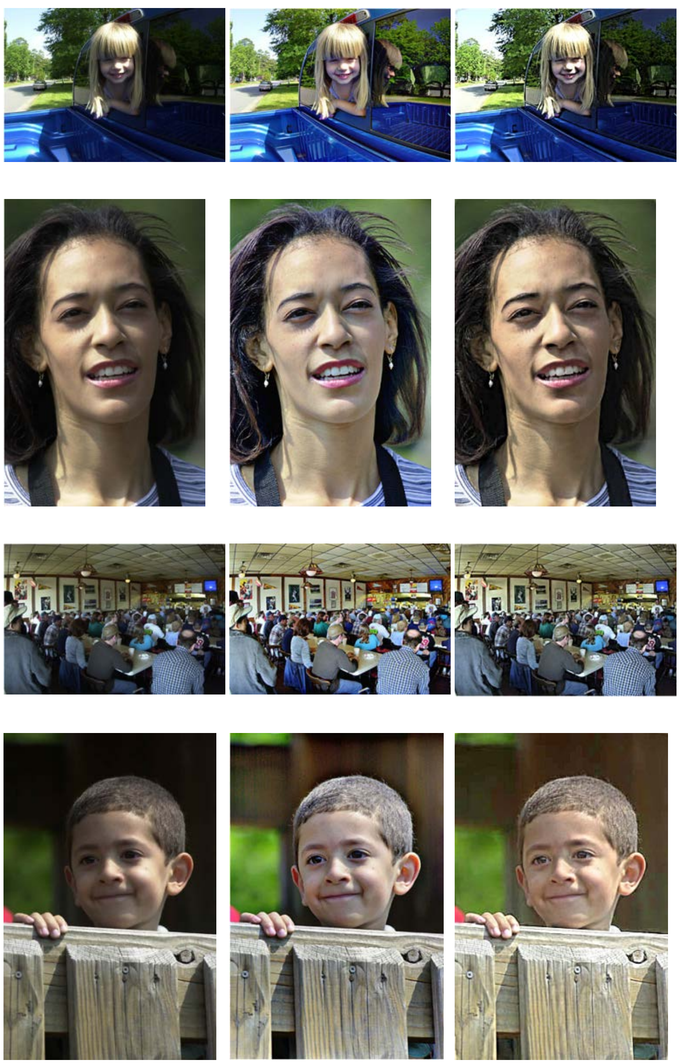
In this section, the computer simulation results are presented to evaluate the effectiveness of the new algorithm. The tested images are borrowed from [6], [13], [14]. Fig. 4 demonstrates the enhancement results on some dark images. The right column illustrates the ability of the new approach in illumination correction. The colors are more distinguishable after final enhancement.

In our simulations, the image is decomposed into two IMFs and a residue and c=3, α=2.5, m=0.5. These values are set experimentally.

Figure 4. Left: Original image; middle: Image after preprocessing; right: enhanced image

Fig. 5 compares the enhancement results by NASA Retinex algorithm and the proposed algorithm of this paper. The images by the proposed method look more natural than Retinex.

Fig. 6 manifests the effectiveness of the new solution for underwater image enhancement. The left column shows the original images.



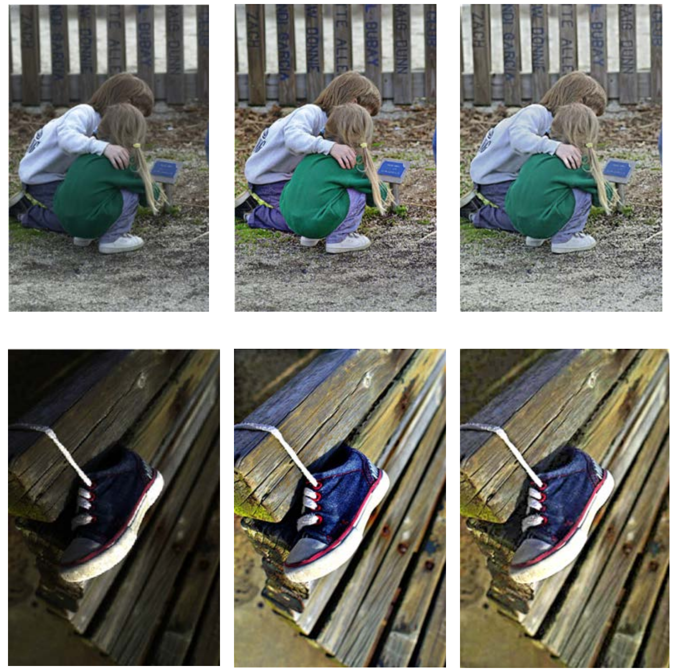


Figure 5. Left: Original image; middle: Image after preprocessing; right: enhanced image

The middle column demonstrates the result after modification of the RGB channels. As observed, the dominance of the blue and green color is significantly reduced. The right column shows the final enhanced image after illumination correction. The results are evident that not only a clear color appearance but also a desirable brightness is achieved.

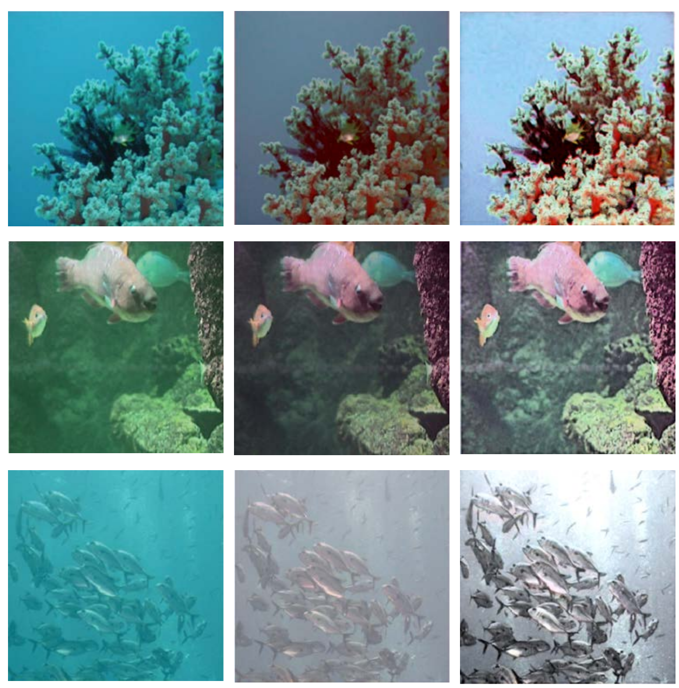


Figure 6. Underwater images; Left: Original image; middle: Image after preprocessing; right: enhanced image

V. CONCLUSION

In this article, an enhancement method was introduced for underexposed images and underwater images. For the underwater images, first, the RGB values were adjusted using GA in order to have an image with the desired mean values in each channel and with a satisfactory quality in the luminance channel. For the dark images, a nonlinear transform was initially applied on the original image to slightly uniform the brightness in whole regions. After these preprocessing steps, a second enhancement was carried out on the luminance of the resulting image using a GA-EEMD based method. The results demonstrated the great performance of the presented algorithm in improving the visual quality of the images in term of color and illumination.

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