High Efficient Algorithm for Colored Image Enhancement Based Upon Dynamic Histogram Stretching

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ABSTRACT — Contrast enhancement is an effective approach for image processing and pattern recognition under conditions of improper illumination. Generally for improving contrast in digital images, Histogram Equalization, HE, based techniques are the methods that commonly used, but they give unnatural artifacts like intensity saturation and noise amplification. In addition, the complexity of these techniques calculation, make them difficult to use in hardware implementation. In this paper, we propose a new mathematical model for improving the contrast of colored images while reducing the complexity of calculation. Our strategy is based upon dynamic histogram stretching. The algorithm first partition the image histogram, for each color channel, into segments, then different transformation function was applied on each partition, according to its contrast value. This mapping operation is based upon the Min-Max linear contrast stretch function. The technique does not require the calculation of the histogram of each partition as the Dynamic Histogram Equalization, DHE, and the Adaptive Histogram Equalization, AHE, methods. Also, there is no need to apply a smoothing filter as the resultant image has less impulsive noise.

The performance of our technique is compared against the HE, the DHE, and the AHE methods. The performance is evaluated with metrics such as Entropy, and Contrast. Experimental results demonstrate that the proposed technique provides better contrast image than the conventional enhancement methods in terms of visual looks and image details, and yet it allows low cost hardware realization.

KEYWORDS — Image Processing, Contrast Enhancement, Contrast Stretching, Histogram Equalization, Histogram Modification, Linear Contrast Enhancements, Non-Linear Contrast Enhancements, Adaptive Equalization, Image Entropy

I. INTRODUCTION

Contrast enhancement is considered to be one of the important issues in image processing. Poor contrast may be due to poor illumination, lack of dynamic range in image sensor, or wrong setting of lens aperture during image acquisition. The idea behind contrast enhancement is to improve the dynamic range of the image pixels and thereby improving the visual quality of the image. Brightness is the general intensity of the pixels in an image. The histogram of an image gives an indication of the brightness. The image is darker when the histogram is confined to a small portion towards the lower end and is brighter when the histogram falls to the higher end.

In the literature, there are some techniques that are used for image enhancement. First of all is the HE. It is a spatial domain method that produces output image with uniform distribution of pixel intensity. In this case the histogram of the output image is flattened and extended systematically [2, 3, 5, 7, 9, 10, 11, 12, 13]. During histogram equalization approach the mean brightness of the processed image is always the middle gray level without concerning of the input mean. The method tends to introduce irrelevant visual deterioration like the concentration effect and it is inevitable that the noises could be amplified or induced simultaneously.

Secondly, DHE was essentially popularized [2, 3, 4, 9, 12, 13], to eliminate the influence of higher histogram components on lower histogram components in the image histogram and to regulate the amount of spreading of gray levels for objective enhancement of the image appearance by using local minima separation of histogram. The histogram is segmented into a number of small regions. Within every small region, the histogram equalization is applied to create the contrast transform function. The new gray level assignments of pixels in each small local region will be specified by this contrast transformation for image enhancement. The gray level mapping from each local histogram is then generated. Through this approach, excessive enhancement of noises will be easily prevented. However, it does not consider the mean brightness preservation. As a result, the local minima will be wrongly misclassified and it increases the complexity of the algorithm.

Another widely used method to enhance the image’s contrast is the AHE [2, 3, 4, 9, 12, 13, 15]. It divides the image into different small parts, called tiles, and the histogram of each is used to redistributes the lightness.
values. So the output of the adaptive histogram is the same as a specified histogram. The neighboring tiles are then combined using bilinear interpolation to eliminate artificially induced boundaries. However, AHE technique has drawback that it results in amplify noise in comparatively homogeneous regions of the image.

Forth, fuzzy logic is used to control the contrast of the image [16, 17]. The technique is based in fuzzify the image, modifying the pixels in the fuzzy domain, then the image goes through defuzzification process. Image contrast using fuzzy logic and Lukasiewicz operators, [16], transforms the levels of the pixels from high to low or from low to high. The bounded sum operator acts as a low pass filter and performs a shift of the pixels to high levels. As a result, a clearer image is obtained. On the other hand, the bounded product operator acts as a high pass filter and displace the histogram towards the black. By combining both operators, a better contrast image is obtained. However, this method does not provide detailed contrast information of the image.

In this paper, we propose a new algorithm for enhancing the contrast of color images by stretching the histogram of each channel dynamically using the min-max linear contrast stretch function [11, 15, 19]. The proposed technique is compared against the HE method, the DHE method and the AHE method in terms of the common quality metrics.

The rest of the paper is organized as follows, section II illustrates the basic principles of the proposed technique. In section III the algorithm is tested and compared with some other methods in the literature. Finally, Section IV offers the conclusion.

II. The dynamic histogram stretch algorithm

The proposed image contrast enhancement technique is described by the following steps:

1) Evaluate the histogram of each channel for the poor RGB color input image.
2) For each channel, identify the bin counts maximums and their corresponding levels. Recognize the largest of the all maximums. Ignore all maximums in which their values are less than 1% of the largest.
3) For each chosen bin counts maximum, identify the levels, at which the counts equals to 5% of the maximum. The difference between the first level above the maximum, Levelmin, and the first level below the maximum, Levelmax, is defined as the bandwidth, BW.
4) Starting from the dark area, the following contrast stretch function is applied for each color channel and for each level:

\[ \text{New Level} = \left( \frac{\text{Old Level} - \text{Level}_{\text{min}}}{\text{Level}_{\text{max}} - \text{Level}_{\text{min}}} \right) \cdot \left( \text{Level}_{\text{New}_{\text{max}}} - \text{Level}_{\text{New}_{\text{min}}(n)} \right) + \text{Level}_{\text{New}_{\text{min}}}. \]

There are some factors need to be considered:

a) For the case of there is a maximum between level zero and the tenth level, consider the Level_{min} equals to zero.
b) For the case of there is a maximum between the 25^{th} level and the 245^{th} level, consider the Level_{max} equals to 255.
c) Test results show that histogram of poor contrast images tend to have only one dominant BW and not more than another one harmonic BW.
d) For the case where the histogram distribution is extremely localized in the dark area. That is the histogram distribution has only one BW segment and its Level_{max} is much less than 128. Then in order to avoid the occurrence of boundary artifacts, which arises from the neighborhoods segments and to obtain an evenly distributed enhancement across most of the entire illumination band, equation (1) needs to be applied first for the segment range from zero till Level_{min}, then again, for the range Level_{min} till Level_{max}, and finally for the range Level_{max} till 255. For the first case, Level_{New_{min}} equals to zero and Level_{New_{max}} should be ≤ Level_{min}. Its value depends upon the contrast of the image. However, for the second case, Level_{New_{min}} is one level above the value of the Level_{New_{max}} of the previous case and Level_{New_{max}} equals to 245. In the third range, Level_{New_{min}} equals to one level above the Level_{New_{max}} of the previous case and the Level_{New_{max}} equals to 255.
e) On the other hand for the case of the histogram distribution is extremely localized in the light area, where the distribution maximum and its Level_{min} are much more than 128. In order to avoid the occurrence of boundary artifacts, which arises from the neighborhoods segments we need to apply equation (1), for the segment range from zero till Level_{min}, then again, for the range Level_{min} till Level_{max} and finally for the range Level_{max} till 255. The Level_{New_{min}} and the Level_{New_{max}} are as follows:

\[ \text{Level}_{\text{New}_{\text{min}}} = \begin{cases} 0 & 0 \leq \text{Old Level} < \text{Level}_{\text{min}} \\ I_1 + 1 & \text{Level}_{\text{min}} \leq \text{Old Level} \leq \text{Level}_{\text{max}} \\ I_2 + 1 & \text{Level}_{\text{max}} < \text{Old Level} \leq 255 \end{cases} \]

\[ \text{Level}_{\text{New}_{\text{max}}} = \begin{cases} 0.25 \text{Level}_{\text{min}} \leq I_1 \leq 0.4 \text{Level}_{\text{min}} & 0 \leq \text{Old Level} < \text{Level}_{\text{min}} \\ \text{Level}_{\text{max}} = I_2 & \text{Level}_{\text{min}} \leq \text{Old Level} \leq \text{Level}_{\text{max}} \\ 255 & \text{Level}_{\text{max}} < \text{Old Level} \leq 255 \end{cases} \]

(2)

The above values resolves the boundary artifacts problem by spreading the gray level of the first segment by about 25%-40% towards the direction of minimum illumination.
f) However, for the case of having two BW segments within the whole illumination band [0 255], the Level\_New\_min and the Level\_New\_max are as follows:

\[
\text{Level\_New\_min} = \begin{cases} 
0 & 0 \leq \text{Old Level} < \text{Level\_min of 1}\_\text{BW} \\
1_{i+1} & \text{Level\_min of 1}\_\text{BW} \leq \text{Old Level} \\
& \& \text{& Level\_max of 1}\_\text{BW} \\
I_{i+1} & \text{Level\_max of 1}\_\text{BW} \leq \text{Old Level} \\
& \& \text{& Level\_min of 2}\_\text{BW} \\
I_{i+1} & \text{Level\_min of 2}\_\text{BW} \leq \text{Old Level} \\
& \& \text{& Level\_max of 2}\_\text{BW} \\
I_{i+1} & \text{Level\_max of 2}\_\text{BW} \leq \text{Old Level} \leq 255
\end{cases}
\]

\[
\text{Level\_New\_max} = \begin{cases} 
0 & 0 \leq \text{Old Level} < \text{Level\_min of 1}\_\text{BW} \\
2.5 & \text{Level\_max of 1}\_\text{BW} = 12 \\
& \text{Level\_min of 1}\_\text{BW} \leq \text{Old Level} \\
& \& \text{& Level\_max of 1}\_\text{BW} \\
I_{i+10} = 13 & \text{Level\_max of 1}\_\text{BW} < \text{Old Level} \\
& \& \text{& Level\_min of 2}\_\text{BW} \\
245 = 14 & \text{Level\_min of 2}\_\text{BW} \leq \text{Old Level} \\
& \& \text{& Level\_max of 2}\_\text{BW} \\
255 & \text{Level\_max of 2}\_\text{BW} < \text{Old Level} \leq 255
\end{cases}
\]

The new gray level assignments of pixels in each segment will be specified by these contrast transformations for image enhancement.

There are some metrics for evaluating the quality of the image. Each one has its own advantages and disadvantages in terms of accuracy, computational speed and type of application. Since, the reference images are not available, it is not appropriate to use the first order statistics measures like the Signal-to-Noise Ratio (SNR), or the corresponding distortion metric, the Mean-Squared Error (MSE), the Absolute Mean Brightness Error (AMBE), and the Contrast-to-Noise Ratio (CNR) \[1, 6, 9, 12, 13\].

On the other hand, the visual characteristics of images are often identified as texture. Since an image is made up of pixels, texture can be defined as an entity consisting of mutually related pixels or group of pixels and thus leading to visual quality of images. Entropy, E, is a measure that relates the Gray Level Co-occurrence Matrix, GLCM, and second order statistics \[1, 9, 21\]. It is used to measure the content of an image and its visual quality. Discrete entropy is a statistical measure of randomness. For image processing, the discrete entropy is a measure of how many bits are needed for coding the image data. A higher value means the image has a richer details. Entropy is defined as:

\[
E = \sum_{i} \sum_{j} P(i,j) \log_{2} \frac{1}{P(i,j)}, \quad (4)
\]

where i and j are two different gray levels of the image, \(P(i,j)\) is the number of the co-appearance of gray levels i and j. Contrast, C, is another second order statistical feature. It is based upon the GLCM and defined as \[1, 9, 21\]:

\[
C = \sum_{i} \sum_{j} (i - j)^{2} P(i,j). \quad (5)
\]

Contrast returns a measure of the intensity difference between a pixel and its neighbor over the whole image. Thus, larger the changes in the gray-scale, the higher the GLCM contrast.

III. EXPERIMENT RESULTS AND DISCUSSION

In order to test the proposed algorithm performance, fifteen colored images are selected. The simulation results of the HE, the AHE, and the DHE are compared with the proposed method, DHS, for these images as shown in figures 1-15. The algorithm has been implemented using Matlab language. Table I and table II show the entropy and the contrast, respectively, values of images 1-11 for different algorithms. Table III and table IV show the entropy and the contrast, respectively, values of images 12-15 for different algorithms. Experimental results demonstrate that the proposed technique gives much better visual characteristics than other methods. The quality of the obtained image using the DHS technique is very notable for all images. It regains the brightness and the color distribution of the original image in a better way than the other methods. The visual superiority arises from the fact that the shape of the image color distribution, (Image histogram) using the DHS algorithm is very close to that of the original image, while other methods deviates from the original. For example, figure 10, shows that the histograms of the three RGB channels, (color distribution), of the DHS algorithm are a stretched version of the three RGB original histograms. Also, The proposed technique does not suffer from intensity saturation and over enhancement as the HE do. In addition, the DHS technique does not suffer from distorted pixels and unnatural contrast enhancement as the AHE and the DHE methods.
Fig. 1. Enhancement results for the IMG01 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).

Fig. 2. Enhancement results for the IMG02 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).

Fig. 3. Enhancement results for the IMG03 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).

Fig. 4. Enhancement results for the IMG04 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).
Fig. 5. Enhancement results for the IMG05 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).

Fig. 6. Enhancement results for the IMG06 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).

Fig. 7. Enhancement results for the IMG07 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).

Fig. 8. Enhancement results for the IMG08 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).
Fig. 9. Enhancement results for the IMG09 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).

Fig. 10. Enhancement results for the IMG10 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique). (f), (k), and (p) are the histograms of the red, green, and blue channels of the original image. (g), (l), and (q) are the histograms of the red, green, and blue channels of the HE image. (h), (m), and (r) are the histograms of the red, green, and blue channels of the AHE image. (i), (n), and (s) are the histograms of the red, green, and blue channels of the DHE image. (j), (o), and (t) are the histograms of the red, green, and blue channels of the DHS image.
Table I shows that the entropy of the enhanced DHS image as compared to others. It is seen that it is higher than the other methods for images 1-11. The obtained image using the DHS algorithm has the richness in details than the other images. On the average, there is an improvement of the DHS entropy over the original image entropy by about 12%. In addition, the entropy of the DHS algorithm is higher than the entropy of the other methods by about 1% - 5%.

Table II shows the contrast value obtained after applying different enhancement techniques on different images. It is seen that the DHS algorithm performs much better than the HE, the AHE and the DHE techniques. It gives the highest contrast value. On the average, the contrast of the DHS algorithm is higher than the average contrast of other methods. It is about 90% higher than the original image and about 20% - 60% higher than the other techniques.

However, the HE method sometimes over enhances the image and introduces intensity saturation and as a result a higher mislead contrast value, than the DHS method, is obtained. The following figures for images 12, 13, 14, and 15 and their associated tables III, and IV, are examples. Even thought the contrast of the HE method for those over enhanced images is higher than that of the proposed DHS algorithm, the output images in this case are worst visually than those of the DHS images. Actually, the DHS images are visually the best.

Table I Comparison of Entropy of all images

<table>
<thead>
<tr>
<th>Images</th>
<th>Original</th>
<th>HE</th>
<th>AHE</th>
<th>DHE</th>
<th>DHS</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMG01</td>
<td>6.706</td>
<td>7.7348</td>
<td>7.77</td>
<td>7.2928</td>
<td>7.7702</td>
</tr>
<tr>
<td>IMG02</td>
<td>6.9138</td>
<td>7.7665</td>
<td>7.7626</td>
<td>7.3301</td>
<td>7.7666</td>
</tr>
<tr>
<td>IMG04</td>
<td>5.9806</td>
<td>5.8623</td>
<td>6.4608</td>
<td>6.454</td>
<td>6.6922</td>
</tr>
<tr>
<td>IMG05</td>
<td>7.4849</td>
<td>7.755</td>
<td>7.9135</td>
<td>7.662</td>
<td>7.9354</td>
</tr>
<tr>
<td>IMG06</td>
<td>7.0806</td>
<td>7.7037</td>
<td>7.8603</td>
<td>7.6235</td>
<td>7.8609</td>
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<td>IMG07</td>
<td>6.1771</td>
<td>7.2768</td>
<td>7.3376</td>
<td>6.9369</td>
<td>7.3505</td>
</tr>
<tr>
<td>IMG08</td>
<td>6.313</td>
<td>7.5689</td>
<td>7.4538</td>
<td>7.1953</td>
<td>7.6065</td>
</tr>
<tr>
<td>IMG10</td>
<td>7.4448</td>
<td>7.9084</td>
<td>7.9461</td>
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<tr>
<td>IMG11</td>
<td>7.004</td>
<td>7.8739</td>
<td>7.797</td>
<td>7.5845</td>
<td>7.8824</td>
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<td>Average</td>
<td>6.6953</td>
<td>7.3377</td>
<td>7.4663</td>
<td>7.1980</td>
<td>7.5361</td>
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Table II Comparison of Contrast of all images

<table>
<thead>
<tr>
<th>Images</th>
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<th>HE</th>
<th>AHE</th>
<th>DHE</th>
<th>DHS</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMG01</td>
<td>0.1688</td>
<td>0.3847</td>
<td>0.3091</td>
<td>0.2155</td>
<td>0.4107</td>
</tr>
<tr>
<td>IMG02</td>
<td>0.4601</td>
<td>1.0178</td>
<td>0.8869</td>
<td>0.5941</td>
<td>1.1254</td>
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<tr>
<td>IMG03</td>
<td>0.2319</td>
<td>0.3429</td>
<td>0.3247</td>
<td>0.3196</td>
<td>0.4822</td>
</tr>
<tr>
<td>IMG04</td>
<td>1.6515</td>
<td>1.4804</td>
<td>1.5421</td>
<td>1.6491</td>
<td>1.9848</td>
</tr>
<tr>
<td>IMG05</td>
<td>0.3884</td>
<td>0.4808</td>
<td>0.5397</td>
<td>0.4448</td>
<td>0.6053</td>
</tr>
<tr>
<td>IMG06</td>
<td>0.6628</td>
<td>0.8955</td>
<td>0.8285</td>
<td>0.8361</td>
<td>1.2515</td>
</tr>
<tr>
<td>IMG07</td>
<td>0.1457</td>
<td>0.6507</td>
<td>0.4652</td>
<td>0.2498</td>
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<tr>
<td>IMG08</td>
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<td>0.405</td>
<td>0.3154</td>
<td>0.2521</td>
<td>0.4724</td>
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<td>IMG09</td>
<td>0.2804</td>
<td>0.7060</td>
<td>0.4521</td>
<td>0.3964</td>
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<tr>
<td>IMG10</td>
<td>0.2726</td>
<td>0.4362</td>
<td>0.4436</td>
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<td>0.4509</td>
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<td>IMG11</td>
<td>0.4107</td>
<td>0.8258</td>
<td>0.7256</td>
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<td>Average</td>
<td>0.4390</td>
<td>0.6933</td>
<td>0.6212</td>
<td>0.5313</td>
<td>0.8358</td>
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</table>
Fig. 13. Enhancement results for the IMG13 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).

Fig. 14. Enhancement results for the IMG14 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).

Fig. 15. Enhancement results for the IMG15 image: (a) Original, (b) HE, (c) AHE, (d) DHE, (e) DHS (our technique).

Table III Comparison of Entropy of some other images

<table>
<thead>
<tr>
<th>Images</th>
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<th>AHE</th>
<th>DHE</th>
<th>DHS</th>
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<tbody>
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<td>IMG12</td>
<td>5.7273</td>
<td>6.0636</td>
<td>6.2431</td>
<td>5.7839</td>
<td><strong>6.2591</strong></td>
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<tr>
<td>IMG13</td>
<td>6.1477</td>
<td><strong>7.7965</strong></td>
<td>7.5509</td>
<td>7.2227</td>
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<tr>
<td>IMG14</td>
<td>6.5774</td>
<td><strong>7.8004</strong></td>
<td>7.6914</td>
<td>7.1409</td>
<td>7.3699</td>
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<tr>
<td>IMG15</td>
<td>6.3782</td>
<td>7.8045</td>
<td>7.619</td>
<td>7.5174</td>
<td><strong>7.8392</strong></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>6.2077</strong></td>
<td><strong>7.3663</strong></td>
<td><strong>7.2761</strong></td>
<td><strong>6.9162</strong></td>
<td><strong>7.3081</strong></td>
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</table>

Table IV Comparison of Contrast of some other images

<table>
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<th>HE</th>
<th>AHE</th>
<th>DHE</th>
<th>DHS</th>
</tr>
</thead>
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<tr>
<td>IMG12</td>
<td>0.0533</td>
<td><strong>0.3592</strong></td>
<td>0.1457</td>
<td>0.1221</td>
<td>0.1934</td>
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<td>IMG13</td>
<td>0.1993</td>
<td><strong>0.9957</strong></td>
<td>0.5579</td>
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<tr>
<td>IMG14</td>
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<tr>
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<td><strong>0.6302</strong></td>
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<tr>
<td><strong>Average</strong></td>
<td><strong>0.2558</strong></td>
<td><strong>0.8887</strong></td>
<td>0.5923</td>
<td>0.4249</td>
<td>0.5534</td>
</tr>
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</table>
IV. CONCLUSION

In this paper, a new image enhancement algorithm based upon dynamic histogram stretching is proposed for underexposed color images. The enhancement effect is evaluated quantitatively and qualitatively. Statistical feature metrics are used for evaluating the image quality after enhancement, especially blind reference images. Simulation results show that the HE suffers from intensity saturation while DHE is not good with preserving brightness of the images. The results show better performance of the DHS technique in comparison to others in terms of entropy, contrast and visual characteristics. The DHS algorithm preserves the naturalness, the effectiveness, and the easiness of implementation while enhancing the low contrast details. The power of the proposed algorithm, DHS, arises from the fact that it improves the contrast of the poor image without affecting the details or introducing any amount of noise in the output image.

REFERENCES
