AN ANALYSIS OF IMAGE QUALITY ASSESSMENT ALGORITHM TO DETECT THE PRESENCE OF UNNATURAL CONTRAST ENHANCEMENT

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ABSTRACT

Image contrast enhancement purposely aim the visibility of image to be increased. Most of these problems may happen after contrast enhancement: amplification of noise artifacts, saturation-loss of details, excessive brightness change and unnatural contrast enhancement. The main objective of this paper is to present an extensive review on existing Image Quality Assessment Algorithm (IQA) in order to detect the presence of unnatural contrast enhancement. Basically, the IQA used produced quality rating of the image while consistently with human visual perception. Current IQA to detect presence of unnatural contrast enhancement: Lightness Order Error (LOE), Structure Measure Operator (SMO) and Statistical Naturalness Measure (SNM). However, result of current IQA evaluation shows it may not giving consistent quality rating with human visual perception. Among three IQAs, SNM demonstrate better performance compared to LOE and SMO. But, it suffers with consistent rating for different spatial image resolution in same image content. Thus, an improvement suggested in this paper to overcome such problem occurred.

Keywords: Contrast Enhancement, Unnatural Enhancement, Contrast Naturalness, Naturalness Quality

1. INTRODUCTION

Image enhancement plays important roles in order to produce a good quality of image in digital imaging area. It comprises image contrast enhancement, image sharpening and image smoothing [1]. The aim of image contrast enhancement is to ensure the visibility of image details increased [2]. Figure 1 illustrate process of contrast enhancement.

![Figure 1. Process Of Contrast Enhancement](image)

Most of these problems may happened after the contrast enhancement: amplification of noise artifacts, saturation-loss of details, excessive brightness change and unnatural contrast enhancement. Figure 2 until figure 5 illustrate image which suffers with stated problems after using global and adaptive histogram equalization.

![Figure 2. Sample Of Amplification Of Noise Artifacts](image)
In order to overcome the problems, IQA is take place since it provides a feedback for the computation achieved the best settings for the contrast enhancement algorithm. Thus, this paper aim is to present an extensive review on existing IQA to detect presence of unnatural contrast enhancement.

2. EXTENSIVE REVIEW OF EXISTING IQA

2.1 Overview of IQA Algorithm

The main purpose of IQA is designed to automatically assess the quality of image with good agreement of human quality evaluation. The evaluation comprises subjective and objective evaluation. The subjective evaluation basically required human as a subject to assess the quality of image. While the objective evaluation is to overcome the weaknesses consist in subjective evaluation since there are limitation of time consuming [3].

The IQA involve two main purposes, first, it is used to assess the optical image quality then automatically adjust the setting to gain the best quality. Second, the algorithm can be embedded into image processing in order to fully optimize the algorithm and achieve optimal design in preprocessing to give the best parameter setting [3].

Generally, IQA can be described into three methods called Full Reference (FR), Reduce Reference (RR) and No Reference (NR). Table 1 illustrate the description of each method.

<table>
<thead>
<tr>
<th>IQA methods</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Reference (FR)</td>
<td>The FR IQA required both reference and its processed image. This method commonly used but the limitation of FR IQA, it is not applicable when the reference image is not available due to reason such as transmission of compressed video/image since the receiver unable to assess the reference image [4].</td>
</tr>
<tr>
<td>Reduced Reference (RR)</td>
<td>The RR IQA required to extract some features of reference image. Number of size used relatively small since it is transmitted together with compressed video/image without affecting the bandwidth [4].</td>
</tr>
<tr>
<td>No Reference (NR)</td>
<td>The NR IQA required no reference image, only processed image. The method basically developed by taking some knowledge in order to estimate the quality of the image. This method most applicable but more complicated since it does not required any assessment to reference image [4].</td>
</tr>
</tbody>
</table>

2.2 Classification of IQAs

The IQA comprises 2D QA, Multimodal QA and 3D QA. Figure 6 illustrate the classification of IQA.
The research is focus on image, thus, 2D QA image quality most applicable to be used. There are two types of techniques under 2D QA image quality called fidelity based and non-fidelity based. The fidelity based consist of general IQA and distortion specific IQA. Most of existing IQA are fidelity based such as assessment of similarity between reference and distorted images. Example of IQA used fidelity based can be found here [5] – [20].

While non-fidelity consist of sharpness and contrast measure and distortion measure. As this research is focus to detect the presence of unnatural contrast enhancement, thus, the review is focus to identify the existence IQA which take non-fidelity based as basis of algorithm designed. The previous works of IQA of non-fidelity based can be found here [21] – [36]. However, existing non-fidelity based algorithm found also not addressing the unnatural enhancement issue.

3. CONTRAST ENHANCEMENT RELATED IQAS

3.1 Contrast and Sharpness Measure Related IQAs

The contrast measure basically used to evaluate the contrast enhanced quality. Table 2 present some of the contrast and sharpness measure.

Table 2: List Of Contrast And Sharpness Measure.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.H. Weber</td>
<td>1834</td>
<td>Weber Contrast [22]</td>
</tr>
<tr>
<td>Albert A. Michelson</td>
<td>1927</td>
<td>Michelson Contrast [21]</td>
</tr>
<tr>
<td>S. S. Agaian, K. Panetta, and A. M. Grigoryan</td>
<td>2000</td>
<td>EME (Measure Of Enhancement By Entropy) [29]</td>
</tr>
<tr>
<td>S. S. Agaian, K. Panetta, and A.</td>
<td>2001</td>
<td>EME (Measure Of Enhancement) [28]</td>
</tr>
</tbody>
</table>

In order to demonstrate the weakness of previous contrast and sharpness measure, the comparison is performed. Figure 7 show image with poor and good contrast level. Result from the contrast measure obtained from [37] presented in Table 3.

Table 3: The Comparison Between Contrast And Sharpness Measures.

<table>
<thead>
<tr>
<th>METRICS</th>
<th>CONTRAST QUALITY (a)</th>
<th>CONTRAST QUALITY (b)</th>
<th>CONTRAST QUALITY (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michelson Contrast</td>
<td>0.432</td>
<td>0.432</td>
<td>0.439</td>
</tr>
<tr>
<td>Weber Contrast</td>
<td>0.101</td>
<td>0.085</td>
<td>0.06</td>
</tr>
<tr>
<td>EME (Measure of Enhancement)</td>
<td>1.36</td>
<td>2.06</td>
<td>3.98</td>
</tr>
<tr>
<td>EME (Measure of Enhancement By Entropy)</td>
<td>0.08</td>
<td>0.13</td>
<td>0.35</td>
</tr>
<tr>
<td>AME (Logarithmic Michelson Contrast Measure)</td>
<td>76.17</td>
<td>68.45</td>
<td>57.31</td>
</tr>
<tr>
<td>AMEE (Logarithmic AME By Entropy)</td>
<td>0.10</td>
<td>0.13</td>
<td>0.18</td>
</tr>
</tbody>
</table>

From the result presented in Table 3, the quality rating keep increasing as long as the contrast level is increase like presented by Michelson, EME, EMEE and AMEE. While some of the quality rating keep decreasing as the contrast level is increase like presented by Weber and AME. Based on this result obtained at here [37], this
shows that the contrast and sharpness measure applicable to evaluate the changes of contrast only.

3.2 IQAs Related to the Problem of Contrast Enhancement
Existing IQA to detect common problem after the contrast enhancement effectively measure by proposed method such as Absolute Mean Brightness Error (AMBE), Entropy and Edge-Based IQA [38]. The AMBE designed to detect changes of overall brightness by taking the absolute difference between average brightness between reference and processed image.

While Entropy, purposely design to measure the uncertainty based on the random variable. Both AMBE and Entropy focus to detect the presence of poor noise and saturation problems in the image. Whereas, the Edge-based aim to detect the presence of annoying distortion by extracting features by using edge detection.

4. IQAS RELATED TO NATURALNESS AND THEIR WEAKNESSES

4.1 Lightness Order Error (LOE)
The LOE is proposed by [39] to design an algorithm based on the relative lightness order. The LOE claimed to measure the naturalness by taking the light source direction and lightness variation. The changes of lightness order between original and its enhanced image indicate the naturalness level. Rating of LOE is high when the lightness order is high, thus high potential for the enhanced image suffer with unnatural contrast enhancement. Figure 8 and Figure 9 show sample of test image tested with LOE.

![Unnatural contrast](image)

(a) (b) (c)

Figure 8 (a) Original image. (b) Good contrast enhancement (LOE = 0.1306). (c) Unnatural contrast enhancement (LOE = 0.1944).

The LOE is proposed by [39] to design an algorithm based on the relative lightness order. The LOE claimed to measure the naturalness by taking the light source direction and lightness variation. The changes of lightness order between original and its enhanced image indicate the naturalness level. Rating of LOE is high when the lightness order is high, thus high potential for the enhanced image suffer with unnatural contrast enhancement. Figure 8 and Figure 9 show sample of test image tested with LOE.

![Unnatural contrast](image)

(a) (b) (c)

Figure 9 (A) Original Image. (B) Good Contrast Enhancement (LOE = 0.0026). (C) Unnatural Contrast Enhancement (LOE = 0.102).

Notice that, Figure 8 (b) is a well enhanced contrast image has LOE = 0.1306 while Figure 9 (c) is suffers from unnatural contrast enhancement has LOE = 0.102. From the result shown, the result given by LOE unable to tell if an image has been well enhanced or unnaturally enhanced. Due to the result obtained, high order change is supposed to give higher rate. The LOE quality is defined as:

$$L(x,y) = \max_{\alpha \in \{L_0, L_1, L_2\}} I^\alpha(x,y)$$

Equation (1) compute the maximum of color channel to find the lightness of image $L(x,y)$.

$$E(x,y) = \sum_{i=1}^{m} \sum_{j=1}^{n} \left( d(L_0(x,y), L_0(i,j)) \cup d(L_2(x,y), L_2(i,j)) \right)$$

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

Equation (2) compute the relative order between original image ($I_0$) and enhanced version ($I_2$) to find the lightness difference for each pixel $(x,y)$. The $m$ and $n$ indicate as height and width of the image. While $U(x,y)$ is the step function to compute the exclusive or operator. The truth table XOR as below:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

$$LOE = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} BD(i,j)$$

Equation (3) is the last stage of LOE computation to produced final rating.

4.2 Structure Measure Operator (SMO)
The SMO is proposed by [40] to design an algorithm based on the structure difference (SD)
between original and enhanced image. The SMO claimed to detect the over enhancement by detecting the changes of structure after he over enhancement based on the non-homogeneity of the image. Rating of SMO is high when the structural change is high, thus high potential for the enhanced image suffer with unnatural contrast enhancement. Figure 10 and Figure 11 show sample of test image tested with SMO.

\[ V_{ij} = \sqrt{\frac{1}{d^2} \sum_{p=-d/2}^{d/2} \sum_{q=-d/2}^{d/2} (b_{ij} - m_{ij})^2} \]  

(6)

Equation (6) compute the standard deviation of image by taking the value of mean intensity, \( m_{ij} \) is computed as in (5).

\[ E_{ij}(p_i) = \frac{1}{d^2} \sum_{l=1}^{d^2} p_i \log_2 p_i, i = 1, ..., n \]  

(7)

Equation (7) compute the entropy of image pixel. Where \( I \) represent the index of the intensity level, \( p \) denotes the probability of the \( i \)th intensity, and \( n \) is the number of intensity levels in the window.

\[ H_{oi} = E_{ij} \times V_{ij} \times H_{ij} \]  

(8)

Equation (8) compute the non-homogeneity value of pixel \( (i,j) \).

\[ SD(G, E_i) = \left| H_{oi} - H_{oi}^{ep} \right| \]  

(9)

Equation (9) compute the structure difference (SD) between the original and enhanced version.

\[ SMO(G, E_i) = \frac{1}{M \times N} \sum_{(i,j)=1}^{M \times N} SD(G, E_i) \]  

(10)

Equation (10) compute the relative structure change of the enhanced image to the original image, SMO.

4.3 Statistical Naturalness Measure (SNM)

The SNM is proposed by [41] to design an algorithm based on the contrast and intensity attribute. The SMO claimed to measure the naturalness by taking the distribution of contrast and intensity based on the collection of 3,000 of 8bits/pixel grayscale image with different types of natural scenery. Rating of SNM is in bound between 0 and 1, where 0 indicate low naturalness and 1 indicate high naturalness level. For SNM evaluation, only result from contrast take into consideration. Figure 12 and Figure 13 show sample of test image tested with SNM.

\[ Unnatural contrast \]

Figure 10 (A) Original Image. (B) Good Contrast Enhancement (SMO = 0.9436). (C) Unnatural Contrast Enhancement (1.515).

Figure 11 (A) Original Image. (B) Good Contrast Enhancement (SMO = 1.6391). (C) Unnatural Contrast Enhancement (SMO = 2.1496).

The examples in Figure 10 and Figure 11 show that SMO is unable to indicate if the image has been well enhanced or unnaturally enhanced. Notice that the SMO of Figure 11(b) is a well enhanced contrast image has SMO = 1.6391 while Figure 10(c) suffers from unnatural contrast enhancement has SMO = 1.515. Due to the result obtained, high structural change is supposed to give higher rate. The SMO quality is defined as:

\[ E_{ij} = \sqrt{S_1^2 + S_2^2} \]  

(4)

Equation (4) compute the edge based on the Sobel Operator where \( S_1 \) and \( S_2 \) is the row and column mask.

\[ m_{ij} = \frac{1}{d^2} \sum_{p=-d/2}^{d/2} \sum_{q=-d/2}^{d/2} (b_{ij} - m_{ij}) \]  

(5)
Since the objective of this paper is to detect the presence of unnatural contrast in enhanced image, thus, for SNM, the evaluation is focus to collect the rating given by contrast distribution only. The contrast quality denote as, $P_d$ is chosen in order to identify either the contrast quality able have good correlation with human visual perception. About 100 test images consist of three contrast level (poor, good and unnatural contrast) were used to test the contrast quality, $P_d$, result obtained shows that most of good contrast image always give highest rating compared to rating for poor and unnatural contrast image. Sample of result shown in Figure 12(b) where the contrast quality, $P_d = 0.8597$ and Figure 13 (b) with contrast quality, $P_d = 0.8252$. However, the problem detected when same image content with different spatial resolution tested as shown in Figure 14.

5. CONCLUSION

Contrast enhancement may cause problems, such as noise artifacts, loss of details, excessive brightness change and unnatural enhancement. IQA is one of the solution to be able design an algorithm to measure the annoyance of the distortion consistent with human visual perception. With that, the contrast enhancement algorithm can automatically assess the image by finding parameter to achieve best result. Existing IQA to overcome mentioned problem after contrast enhancement are Edge-Based, Entropy and AMBE respectively except for unnatural contrast enhancement. The preliminary findings to detect the presence of unnatural contrast enhancement shows that LOE and SMO may give inconsistent in the rating. While the contrast rating in SNM, almost give promising rating to solve the problem. However, notice there are some inconsistent rating given by contrast quality when applied on the different spatial resolution.

REFERENCES:


