

Contrast Enhancement using Non-overlapped Sub-blocks and Local Histogram Projection

Bin Liu, Weiqi Jin, Yan Chen, Chongliang Liu, and Li Li

Abstract—*Contrast enhancement regarded as a significant branch of image processing, not only enhances human perception of details hidden in the scene, but also improves the rapid recognition of interested targets. In this paper, a non-overlapped sub-blocks and local histogram projection based contrast enhancement (NOSHP) is presented. First, the original image is segmented into numbers of non-overlapped sub-blocks where the histogram projection (HP) is then executed individually. Subsequently, each sub-block is related to its adjacent three ones by certain weights, so that the integral image and local details can be both enhanced. Experiments in this paper approve that NOSHP can effectively enhance the local details as well as properly preserve the image brightness to avoid the annoying blocking effect and wash-out effect. Moreover, this algorithm can dramatically reduce the time consumption in practical use, leading to a useful real-time processing method well suited to the consumer electronic products.*

Index Terms—**Contrast Enhancement, Histogram Projection, Histogram Statistical Stretching, NOSHP**

I. INTRODUCTION

Contrast enhancement, considered as a kind of significant image processing both for images and videos, can effectively improve the image visual quality and increase the image contents for human perception and recognition. In addition, it is also an important preprocessing method to provide the high-performance images and videos to pattern recognition, machine vision and other applications.

Histogram equalization (HE) based contrast enhancement which is still widely used in the literature can be categorized into two parts: global histogram equalization (GHE) [1]-[4] and local histogram equalization (LHE) [5]-[7]. GHE based algorithms compute the cumulative distribution function (CDF) by using the probability distribution function (PDF) of the original image, and accomplish the contrast enhancement by CDF mapping. The purpose of GHE is to make the PDF of the original image be distributed equally on the full grayscale range as shown in Fig.1 (But in reality, the PDF can not be ideally distributed because of the discrete characteristics of the digital image [8]). Therefore, GHE based algorithms can only enhance the high-PDF grayscales, while the low-PDF ones can not be easily

improved. Owing to grayscale combination and compression, GHE based algorithms could definitely result in loss of details. Besides that, they could also change the image brightness, leading to the wash-out effect [9], [10]. In order to overcome the drawbacks mentioned above, LHE based algorithms are proposed, in which HE is executed in a finite region determined by a predefined sliding window. By moving the sliding window pixelwisely, the contrast enhancement could be completed until all the pixels in the image are successfully processed. LHE based algorithms only equalize pixels in the finite region, thus they could effectively reduce the impact of other regions, and greatly enhance the local details. However, there is one significant shortcoming in LHE that they are much time consuming and complex in real-time applications. Take an image of 640×480 resolution for example, the quantity of implementing HE will come to 307200 times [11], so it is not easy to introduce LHE in the real-time processing systems. To decrease the expensive computation as well as retain the feature of local detail enhancement, a non-overlapped sub-blocks based HE is presented. It partitions the original image into numbers of non-overlapped sub-blocks, and then implements HE in every single sub-block individually. Though the advantages of low time consumption and proper local detail enhancement are attractive, there is still an inconvenient drawback we must face—the blocking effect as shown in Fig. 2.

Based on the requirement of real-time processing, Kim *et al* proposed a contrast enhancement using partially overlapped sub-block histogram equalization (POSHE) to deal with both the contrast enhancement and blocking effect [11]. In this algorithm, it partitions the original image into numbers of sub-blocks, and then equalizes them in terms of partially overlapped manner, and finally averages the result based on certain weights. POSHE could be considered as a special version of LHE, thus it has all the features belonging to LHE besides its own. Namely it could well strengthen the local details as well as decrease the wash-out effect and blocking effect. Moreover, it is capable of accelerating the processing to achieve the real-time applications. However, if we inspect the results carefully, slight blocking effect still exists in the images though blocking effect reduction filter (BERF) operation suggested by Kim is already conducted. More detail description and further improvement about the POSHE-like algorithms refer to [11], [12].

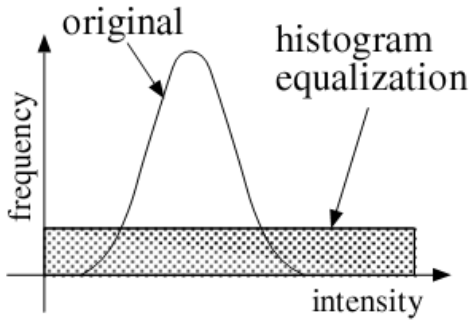


Fig.1. GHE Process



Fig.2. Non-overlapped Sub-blocks based HE Process

No matter GHE, LHE or POSHE, the HE process is always the fundamental for these three methods. Therefore, HE based algorithms are not the optimal choices for contrast enhancement, especially when dim texture and tiny targets are what we concern most. Different from HE process, HP based algorithms work on the fact that zero-PDF grayscales sometimes exist in the original histogram, and they can enhance the contrast by redistributing the original grayscales uniformly onto the full grayscale range [2], [13]. The schematic diagram of HP process is shown in Fig. 3. They could preserve the image brightness as far as possible, and avoid the annoying wash-out effect as well. HP based algorithms regarded as the global enhancement methods, could still bring about mutual influence among different regions, namely some parts of the image are improved, while others are not. Subsequently, a non-linear mapping based HP algorithm is proposed, which enhances the contrast by non-linearly adjusting the original histogram [4]. It is indeed better than those traditional ones, but the non-linear mapping curve is not easily and automatically acquired in practical uses. In order to appropriately enhance the contrast and highly decrease the time consumption and complexity, in this paper we present the NOSHP to deal with these problems. It not only has efficient performance similar to the global methods like GHE and HP, but also owns detail enhancement of perfect visual perception similar to the LHE and POSHE.

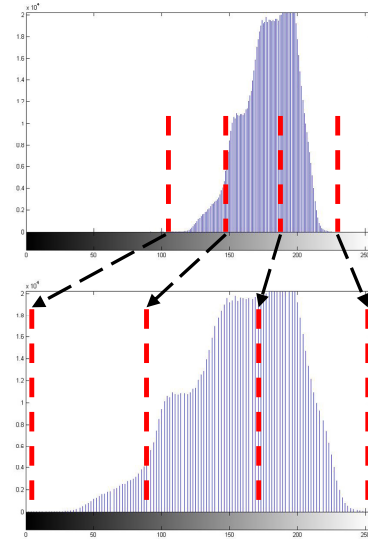


Fig.3. HP Process

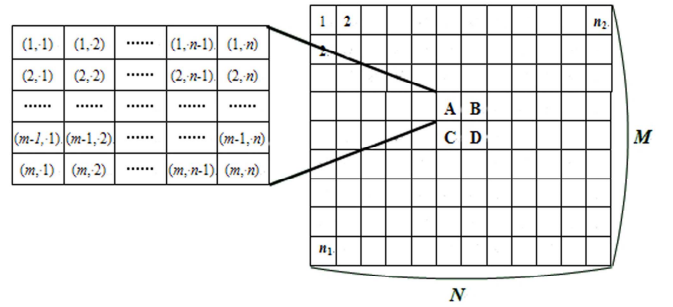


Fig.4. Sub-blocks Segmentation

II. ALGORITHM FRAMEWORK

A. Visible Image Processing

When the original image is $M \times N$ and each sub-block is determined to be $m \times n$, then the quantity of sub-blocks in the image is $n_1 \times n_2$ ($n_1 = M/m$, $n_2 = N/n$) as illustrated in Fig. 4. The processing steps of NOSHP are as follows.

Step 1. Calculate the PDF of the original image and count the nonzero-PDF grayscales.

$$PDF_A(k) = \frac{p_k}{P_A} \quad k = 0, 1, 2, \dots, 255 \quad (1)$$

$$flag_A(k) = \begin{cases} 1 & PDF_A(k) > 0 \\ 0 & PDF_A(k) = 0 \end{cases} \quad k = 0, 1, 2, \dots, 255 \quad (2)$$

$$C_A(z) = \sum_{k=0}^z flag_A(k) \quad z = 0, 1, 2, \dots, 255 \quad (3)$$

Where $PDF_A(k)$ denotes the PDF value of k th grayscale in sub-block A , p_k and P_A depict the pixels of k th grayscale and all the pixels in sub-block A respectively. $flag_A(k)$ is a statistical flag for the k th grayscale in sub-block A , of which 1 is for the nonzero PDF, and 0 is for the zero PDF. $C_A(z)$ represents the cumulative function.

Step 2. According to the HP process, we can obtain the mapping functions as below.

$$T_A(z) = 255 * c_A(z), \quad z = 0, 1, 2, \dots, 255 \quad (4)$$

Where $c_A(z) = C_A(z)/C_A(255)$ is the normalization of $C_A(z)$, and $c_A(255) = 1$. The same operations are also executed in the adjacent three sub-blocks B , C , and D to acquire the corresponding mapping functions respectively.

$$\begin{aligned} T_B(z) &= 255 * c_B(z), & z &= 0, 1, 2, \dots, 255 \\ T_C(z) &= 255 * c_C(z), & z &= 0, 1, 2, \dots, 255 \\ T_D(z) &= 255 * c_D(z), & z &= 0, 1, 2, \dots, 255 \end{aligned} \quad (5)$$

Step 3. To avoid the blocking effect, we relate the four adjacent sub-blocks by certain weights to decrease the brightness discontinuity on the block boundary, and the weights, which are related to the positions in the sub-block, can be obtained automatically. The final result can be expressed by the formula as below [14], [15].

$$\begin{aligned} g_A(x, y) &= \frac{1}{(m+1)(n+1)} [T_A(f_A(x, y))(m+1-x)(n+1-y) \\ &+ T_B(f_A(x, y))x(n+1-y) + T_C(f_A(x, y))y(m+1-x) \\ &+ T_D(f_A(x, y))xy] \quad (x, y) \in A \end{aligned} \quad (6)$$

Where $f_A(x, y)$ is the gray value at the position (x, y) in sub-block A , and $g_A(x, y)$ is the output related to $f_A(x, y)$. It shows in (6) that $g_A(x, y)$ is generated from $f_A(x, y)$ not only by the mapping function of sub-block A , but also the adjacent three sub-blocks. The formula we implement here is to reduce the irrational local contrast enhancement for every single sub-block, meanwhile strengthen the relationship of the neighboring sub-blocks to achieve the integral improvement and local enhancement. Further discussions about (6) are as follows. Take the condition of x varying from 1 to m for instance. When x is small (for example $x=1, y=1$), $T_A(f_A(x, y))$ weighs more to form $g_A(x, y)$ than the other three mapping functions, thus $g_A(x, y)$ is similar to $T_A(f_A(x, y))$. Contrarily, when x is large (for example $x=m, y=1$), $T_B(f_A(x, y))$ weighs more to form $g_A(x, y)$, and $g_A(x, y)$ is similar to $T_B(f_A(x, y))$. Consequently, gray values in the region between sub-block A and B would be well smoothed, and the blocking effect is successfully eliminated. The analysis about y is very similar to x , thus the final result shows the good visual quality without any inconvenient wash-out effect and blocking effect.

B. Infrared Image Processing

The infrared image commonly represents the infrared radiation of the scene. When a few of outliers (small objects overheated or colder than the background) or residual bad pixels exist in the image, the dynamic range of the scene will be heavily suppressed when displayed on a regular monitor, and it would result in low temperature resolution and blurry objects. Histogram statistical stretching (HSS) we presented in this paper is adopted to reduce the dynamic range compression (DRC) caused by these outliers before NOSHP is executed. HSS is used to primarily improve the dynamic range and contrast of the infrared images. The processing steps are listed as below.

Step 1. Calculate the PDF of the original image and determine the maximum PDF and its location on the grayscale range.

$$\max_{\text{hist}} = \max(\text{hist}_{\text{origin}}) \quad (7)$$

$$g_{\text{hist}} = \text{position}(\max_{\text{hist}}) \quad (8)$$

Where $\text{hist}_{\text{origin}}$ represents the original histogram; $\max()$ and $\text{position}()$ are functions used to find the maximum PDF and locate its position; \max_{hist} and g_{hist} are the maximum PDF and its corresponding position on the grayscale range.

Step 2. Sum the PDF from both sides of g_{hist} in an interlaced manner and set a proper threshold to stop the cumulative process.

$$\text{hist}_{\text{sum}} = \sum_{k=g_{\text{hist}}-m}^{g_{\text{hist}}+m} p_r(k) = \sum_{k=g_{\text{hist}}-m}^{g_{\text{hist}}+m} \frac{n_k}{n}, \quad \text{if } \max(\text{hist}_{\text{sum}}) \leq \text{Threshold}_{\text{HSS}} \quad (9)$$

$$m = 0, 1, 2, \dots, L-1$$

Where $p_r(k) = n_k/n$ is the PDF of k th gray level; n_k and n are pixels of k th gray level and the total pixels in the image respectively; m represents the distance far away from g_{hist} in terms of grayscale quantity; L is the grayscale range which equals 256 when 8bits image is taken for example; $\text{Threshold}_{\text{HSS}}$ is the threshold we manually set in (9) to halt the cumulative process. The process we usually encounter can be categorized into two situations.

a). Normal situation: if the threshold is met, then $\min_value = g_{\text{hist}} - m$, $\max_value = g_{\text{hist}} + m$.

b). Abnormal situation: when the PDF of gray level $g_{\text{hist}} - m$ comes to zero during the cumulative process, then $\min_value = g_{\text{hist}} - m$. Subsequently, the gray levels greater than g_{hist} are only considered and summed in the cumulative process until the threshold is met, and then $\max_value = g_{\text{hist}} + m'$, or vice versa. Fig. 5 shows the differences of \min_value and \max_value in the normal and abnormal situations. The cumulative process we conduct here is to take full advantage of the active grayscales in the original image, so as to expand the active dynamic range and get rid of the useless grayscales.

Step 3. Histogram stretching is then executed after the \min_value and \max_value are successfully obtained.

$$q(k) = \begin{cases} 0 & \text{if } k < \min_value \\ \frac{255}{2m} (k - \min_value) & \text{if } k > \max_value \\ \text{others} & \text{others} \end{cases} \quad (10)$$

Where $q(k)$ denotes the mapping function from the original image to the result. The dynamic range of the image is much improved after HSS processing as shown in Fig. 6, and the details hidden in the original image are primarily enhanced as well.

Step 4. Moreover, the local details will be further strengthened after NOSHP. Besides the infrared images of 8bits data, those of 14bits data are also tested in our experiments and they all achieve the good visual perception.

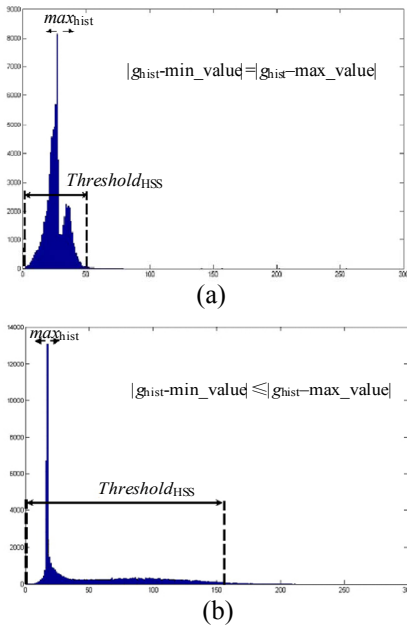


Fig.5. Normal (a) and Abnormal (b) Situations

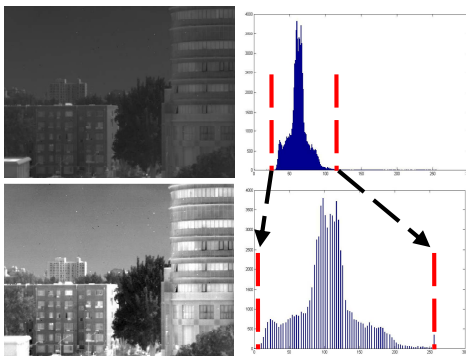


Fig.6. HSS Process

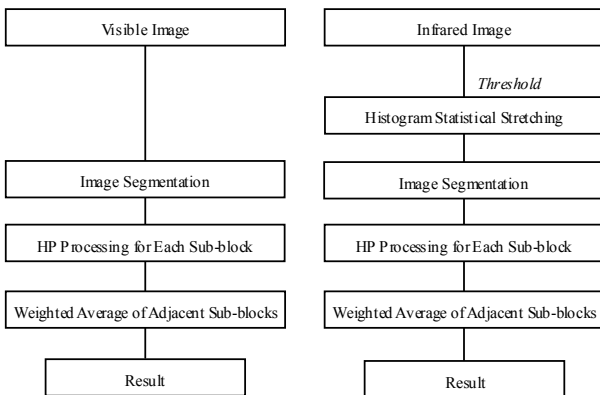


Fig.7. Flowchart of NOSHP for Visible and Infrared Image

III. ANALYSIS AND EVALUATION

A. Time Consumption

The flowchart of NOSHP for the visible and infrared images is shown in Fig. 7. Other kinds of images such as magnetic resonance imaging (MRI), positron emission computed

tomography (PET), radar imaging, etc., could also be enhanced by this algorithmic framework only if a certain proper revision is made.

The time consumption is taken as an objective evaluation to assess these algorithms (The time consumption of implementing HE or HP once is considered as the unit time). GHE consumes the least time to accomplish its process as well as HP, and POSHE requires $(2n_1-1) \times (2n_2-1)$ times of HE process to produce the final result (BERF de-blocking operation is ignored). The NOSHP implements only $n_1 \times n_2$ times of HP process to reach the final result. In Table 1, though NOSHP is slightly slower than HE and HP, it is still qualified to conduct the real-time processing due to its speed faster than POSHE.

B. Subjective Evaluation

The visible images enhanced by HP, GHE, POSHE and NOSHP are shown in Fig. 8(b) to (e) respectively. Owing to lack of zero-PDF grayscales in the original histogram, the image enhanced by HP is very similar in visual perception to the original image as shown in Fig. 8(a). The background of Fig. 8(a) represents the dominant grayscales, so that the image enhanced by GHE shows excessive contrast in the background area, while the interested targets composed of low-PDF grayscales have less contrast, for example the target marked by a rectangle in Fig. 8(c). If the detail perception is only considered in mind, POSHE could outperform both HE and HP, especially for the target marked by a rectangle in Fig. 8(d). Because the blocking effect is inevitable in the image produced by POSHE, it is not well qualified for visual perception and object recognition. In Fig. 8(e), it shows that the visual perception of the image processed by NOSHP is superior to the others in terms of local detail perception and brightness preservation. In this image the local details are well enhanced as well as the blocking effect is successfully eliminated. For example, roads around the pentagon and other interested targets could all be observed, especially the contrast of the target marked by a rectangle in Fig. 8(e) is much improved with the best appearance.

The contrast enhancement for the infrared image is shown in Fig. 9. HP processing in Fig. 9(b) is very similar to the original image in Fig. 9(a) due to the same reason as mentioned in the visible case. Indeed, GHE processing in Fig. 9(c) enhances the contrast of the dark region, while in other regions, it becomes worse. In addition the wash-out effect is explicitly shown in the image. Similar to the visible case, POSHE is quite capable of dealing with the local contrast enhancement. Nevertheless, the blocking effect and the wash-out effect decrease the human perception of the scene, for example the wash-out effect exists in the area marked by a rectangle as shown in Fig. 9(d). NOSHP processing is shown in Fig. 9(e), from which the detail perception is much superior to HE and HP, and in some local regions it outperforms POSHE too. For example the building structure is over enhanced in the center of Fig. 9(d), so that it seems unnatural and unreal. While in Fig. 9(e) the building structure is much clearer than Fig. 9(a) to (c), and the brightness is also well preserved

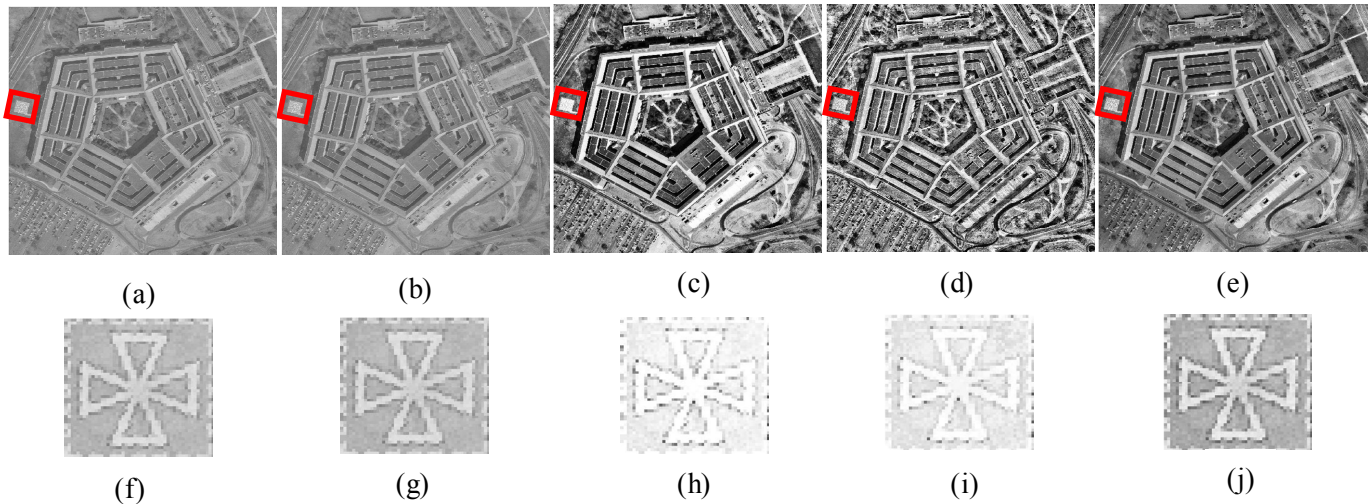


Fig.8 Visible results by different algorithms. (a) Original visible image; (b) HP processing; (c) GHE processing (d) POSHE processing; (e) NOSHP processing; (f)-(j) magnified interested detail marked by a rectangle in (a) to (e)

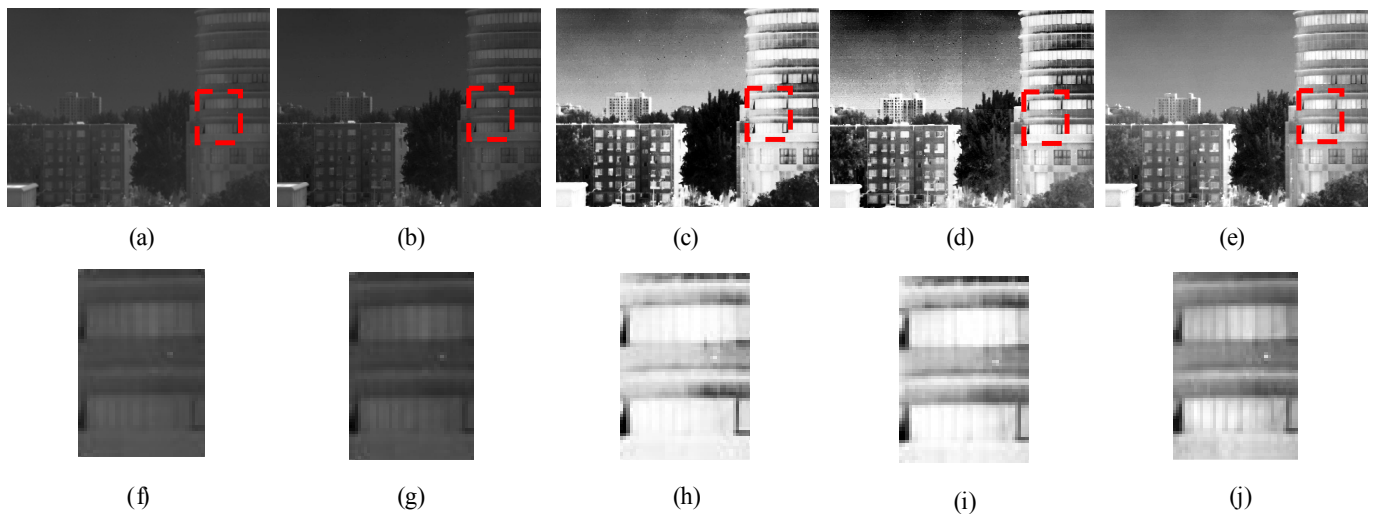


Fig.9 Infrared results by different algorithms. (a) Original infrared image; (b) HP processing; (c) GHE processing (d) POSHE processing; (e) NOSHP processing after HSS; (f)-(j) magnified interested detail marked by a rectangle in (a) to (e)

TABLE I
TIME CONSUMPTION AND OBJECTIVE ASSESSMENT

	Original	HP	GHE	POSHE	NOSHP
HE(HP) Implementation	—	1	1	$(2n_1-1) \times (2n_2-1)$	$n_1 \times n_2$
Entropy	4.667	4.667	4.104	5.315	5.525
EME	20.212	20.212	377.624	387.135	300.790

C. Objective Evaluation

Besides the subjective evaluation approves the effectiveness and performance of NOSHP, moreover we still need objective criterions to assess NOSHP in a scientific way. Here the entropy is employed [8], [16], [17]. The discrete entropy is used to measure the content of an image, where a higher value indicates the image with richer details. Recently a new criterion for the contrast enhancement called measure of enhancement (EME) has been proposed [18], [19]. The EME approximates an average contrast by partitioning the image into numbers of non-overlapped sub-blocks, and then finding a measure based

on the minimum and maximum gray values in each sub-block, and finally averaging them to generate the final result. The entropy and EME of Fig. 8 are shown in Table 1. The entropy of GHE is less than that of the original image. That is because the grayscale combination and compression occur after GHE. While the entropy of POSHE is much higher than that of the original image due to its great performance to the local details. The NOSHP algorithm we presented in this paper not only effectively preserves the brightness, but also successfully enhances the local details. Therefore, the entropy of NOSHP is the highest of all. The EME evaluation usually generates a higher value when there is larger variation of gray values in a

sub-block. Based on this conception, GHE and POSHE both achieve the high value. The EME value of NOSHP seems slightly lower than that of GHE and POSHE, but the local detail perception and the proper brightness are the best for the human visual perception.

Under the consideration of time consumption and algorithmic flexibility, in this algorithm the image segmented into 4×4 to 8×8 sub-blocks is recommended. In our experiments, we segment the image into 6×6 sub-blocks for example.

IV. CONCLUSION

In this paper, we present an effective contrast enhancement method based on non-overlapped sub-blocks and local histogram projection. By partitioning the original image into numbers of non-overlapped sub-blocks and relating each sub-block with its adjacent neighbors, we can properly enhance the contrast of local details as well as avoid the blocking effect and the wash-out effect in the result. The image processed by the NOSHP is with the rational brightness and good visual perception. The experiments in this paper approve that NOSHP is effective, efficient and flexible. And moreover, it is quit qualified to be a real-time processing method in the consumer electronic products.

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BIOGRAPHIES



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