An Image Contrast Enhancement Algorithm Using PLIP-based Histogram Modification

Zhou Zhao, Yicong Zhou
Department of Computer and Information Science
University of Macau, Macao, China
yb67412@umac.mo, yicongzhou@umac.mo

***Abstract*—Contrast enhancement is an important tool for producing informative and visually pleasing images. However, conventional image contrast enhancement methods often suffer from the drawback of excessive enhancement. In this paper we propose a new image contrast enhancement algorithm. It embeds PLIP operations into a robust histogram modification framework. Experimental results demonstrate that the proposed algorithm can effectively enhance image contrast while preventing excessive enhancement.**

***Index Terms*—contrast enhancement, parameterized logarithmic image processing, histogram modification**

I. Introduction

Image contrast is always directly associated with image quality. Images with higher contrast are usually more visually pleasing and informative to human viewers. However, the contrast of images can be undesirable due to various reasons such as low-quality imaging devices, lack of expertise of users and poor illumination condition. Contrast enhancement targets to improve the informativeness and visual quality of raw images, and it has been an active research topic in computer vision and digital image processing for a long history.

Histogram equalization (HE) is one of the most commonly used contrast enhancement techniques. HE uses the cumulative density function to obtain uniformly distributed histogram [1]. It is effective in stretching contrast and revealing details. However, standard HE often results in excessive enhancement and adds artifacts to the output.

Various methods have been developed to overcome the drawbacks of HE. To limit the level of enhancement, a contrast limited adaptive histogram equalization (CLAHE) [2] is proposed. It clips values above a certain level in the local histogram, so that the amount of enhancement on each pixel is limited. However, this method has trouble in preserving brightness and may bring visible distortion to the output. Methods such as brightness preserving bi-histogram equalization (BBHE) [3] and dualistic sub-image histogram equalization (DSIHE) [4] divide an input image histogram into sub-histograms and perform HE on each sub-histogram. These methods generate more visually pleasing results than HE, but the improvement is limited and they are sensitive to noise. Recently, Gu et al. proposed a robust image contrast enhancement (RICE) [5] model, which is effective in suppressing overenhancement, but its performance on low contrast images is often undesirable.

In order to design an effective method for image contrast enhancement, we look into the logarithmic image processing (LIP) [6] model, which is a nonlinear arithmetic framework. It was designed to tackle the problems in image processing methods with linear arithmetic operations, and has been adopted for various applications such as image enhancement [7] and edge detection [8]. The parameterized LIP (PLIP) model further improves the LIP model by introducing a set of parameters [9]. Using the PLIP operations instead of linear operations, the performance of conventional image enhancement methods can be significantly improved.

In this paper, we introduce a new image contrast enhancement method. It combines the idea of histogram modification with nonlinear operations from the PLIP framework. The proposed method is capable of effectively enhancing image contrast while preventing over-enhancement.

The rest of the paper is organized as follows: section 2 briefly discusses several common PLIP operations. The proposed algorithm is introduced in section 3. Section 4 presents the experimental results. A few concluding remarks are given in section 5.

II. PLIP operations

By replacing linear operations with PLIP operations, PLIP properly represents the nonlinearity characteristics of images, and gives users more flexibility to choose different parameters in order to obtain the most desirable outcome. A list of common PLIP operations is presented in Table 1 [9].

TABLE I: PLIP Operations

PLIP Operation	Definition
Gray-tone function	$g(i,j) = \mu - f(i,j)$
Addition	$g_1 \widetilde{\oplus} g_2 = g_1 + g_2 - \frac{g_1 g_2}{\gamma}$
Subtraction	$g_1 \widetilde{\ominus} g_2 = k \frac{g_1 - g_2}{k - g_2}$
Scalar multiplication	$c \widetilde{\otimes} g_1 = \gamma - \gamma(1 - \frac{g}{\gamma})^c$

$f(i,j)$ is the original image intensity, $g(i,j)$, g_1, g_2 are the gray-tone functions; μ, γ, k, are PLIP parameters; $\widetilde{\oplus}$, $\widetilde{\ominus}$ and $\widetilde{\otimes}$ are PLIP operators for PLIP operators for addition, subtraction and scalar multiplication respectively.

978-1-5386-2201-8/17/$31.00 ©2017 IEEE

(a) (b) (c)

Fig. 1: Comparison between HE and PLIP-HE. (a) The original image; (b) Image processed by HE (c) Image processed by PLIP-HE.

The choice of parameter μ could be image dependent, such as the greatest value of the image intensity, for example $\mu = 255$. It could also be any other positive values, such as $\mu = 800$. γ and k can also be chosen as any positive value.

Under the PLIP framework, an input image is firstly transformed into a gray-tone image, then all linear operations such as addition, subtraction should be replaced with PLIP operations accordingly. Fig. 1 shows a comparison of the standard HE and modified HE using PLIP operations. As we can see, using PLIP operation can significantly improve the performance of HE, producing an image with higher contrast and less over-enhancement.

III. Proposed Algorithm

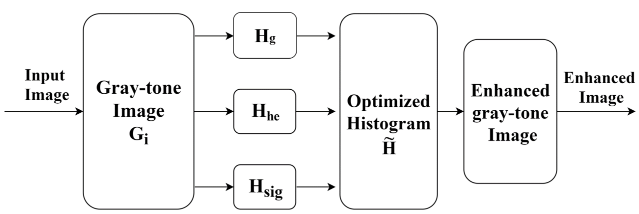

Fig. 2: Block diagram of the proposed algorithm

In this section, we propose a new image contrast enhancement method utilizing PLIP operations. Its block diagram is depicted in Fig. 2. The algorithm mainly works in two stages: 1) to generate histograms H_g, H_{he} and H_{sig}; 2) to calculate an optimal histogram $\tilde{H}$ using the results obtained in Stage one. The enhanced image is produced by histogram matching.

Given an input image $F(m, n)$, firstly, it is transformed into a gray-tone image using the gray-tone function:

$$G_i(m, n) = \mu - F(m, n) \tag{1}$$

The histogram of gray-tone image $G_i(m, n)$ is denoted by H_g.

H_{he} represents a uniformly distributed histogram, it can be obtained by performing the PLIP Histogram Equalization (PLIP-HE) on $G_i(m, n)$. PLIP-HE can be defined by the following histogram matching function:

$$L(I) = I_{min} \widetilde{\oplus} (I_{max} \widetilde{\ominus} I_{min}) \widetilde{\otimes} C(I) \tag{2}$$

where I is the input intensity value, I_{min} and I_{max} are the minimum and maximum values of the desired output intensity range, $C(I)$ is the cumulative density function calculated from H_g where $C(I_{max}) = 1$, $L(I)$ represents the output intensity.

Another component is required in order to effectively preserve brightness and prevent over-enhancement. Gu et al. proposed a brightness preserving contrast enhancement method based on sigmoid function [10]. Embedding PLIP operations into the sigmoid transformation, we introduce the PLIP sigmoid transformation (PLIP-ST) defined by:

$$G_{sig} = T_{sig}(G_i, s) = \frac{s_1 \widetilde{\ominus} s_2}{1 \widetilde{\oplus} exp(-\frac{(G_i \widetilde{\ominus} s_3)}{s_4})} \tag{3}$$

where $s = \{s_1, s_2, s_3, s_4\}$ are parameters that can be solved using the method proposed in [10]. Because the S-shaped transform curve of the sigmoid transformation should be symmetric with respect to the central intensity value, we assume the curve pass through several points, specifically, $(x_1, y_1) = (0, 0)$, $(x_2, y_2) = (128, 128)$, $(x_3, y_3) = (255, 255)$, x_4 is set to be 25 and y_4 is a free parameter.

The optimal parameters $s = \{s_1, s_2, s_3, s_4\}$ can be calculated by minimizing the value of the following function:

$$s_{opt} = \arg\min_s \sum_{i=1}^{4} |y_i - T_{sig}(x_i, s)| \tag{4}$$

After determining the optimal parameters, we can use the PLIP-ST to generate $G_{sig}(m, n)$:

$$G_(sig) = T_{sig}(G_i, s_{opt}). \tag{5}$$

The histogram of G_{sig} is denoted by H_{sig}.

Using histograms H_g, H_{he} and H_{sig}, we produce an optimal histogram [5]:

$$\tilde{H} = \frac{H_g + \phi H_{he} + \psi H_{sig}}{1 + \phi + \psi} \tag{6}$$

where $\{\phi, \psi\}$ are a pair of parameters, selecting deferent ϕ and ψ will result in deferent tradeoffs between the original gray-tone image, the gray-tone image after PLIP-HE and the gray-tone image produced by PLIP-ST.

Given $\tilde{H}$, the same histogram matching function in equation (2) can be used to produce $\tilde{G}$. Finally, the enhanced image

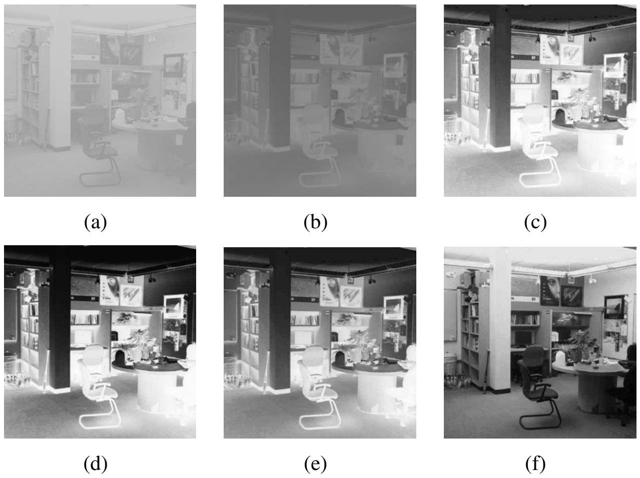

Fig. 3: An illustrative example of the proposed algorithm. (a) Original image; (b) gray-tone image $G_i(m,n)$; (c) gray-tone image generated by PLIP-HE; (d) gray-tone image $G_{sig}(m,n)$ generated by PLIP-ST; (e) gray-tone image $\tilde{G}$ generated by histogram matching; (e) enhanced image.

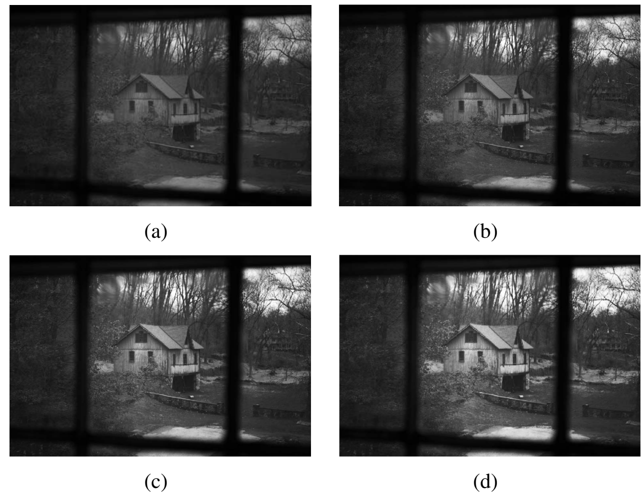

Fig. 4: Image enhancement using different parameter settings. (a) The original image; (b) enhanced image with $\phi = 0.1$, $\psi = 0.08$, $\mu = \gamma = k = 300$; (c) enhanced image with $\phi = 0.3$, $\psi = 0.02$, $\mu = \gamma = k = 300$; (d) enhanced image with $\phi = 0.3$, $\psi = 0.02$, $\mu = \gamma = k = 800$.

$E(m,n)$ can be obtained by transforming gray-tone image $\tilde{G}(m,n)$ back to gray-scale image using the same gray-tone function as equation (1):

$$E(m,n) = \mu - \tilde{G}(m,n). \tag{7}$$

Fig. 3 shows the results of each step in the proposed algorithm. The input image is transformed into its negative using the gray-tone function; PLIP-HE and PLIP-ST are applied on the gray-tone image; their histograms of the results are used to compute a optimized histogram; the enhanced gray-tone image is transformed back to gray-scale image after histogram matching.

IV. Experiment results

A. Parameter selection

The selection of ϕ and ψ is image dependent. When processing images with higher contrast, we may want to choose larger ϕ and smaller ψ in order to preserve image brightness and prevent over-enhancement. On the other hand, when processing low contrast images, larger ϕ is used in order to stretch the image contrast. Choosing different PLIP parameters, we can tune the finer details of the enhanced images.

As shown in Fig. 4, using different $\{\phi, \psi\}$ can change the overall enhancement effect. Changing the PLIP parameters, the sensitivity of the algorithm can be modified. The parameters are selected in terms of the optimal visual effect or the maximum result of quantitative measures.

B. Performance comparison

Several experimental results are presented in this section. We compare the proposed method with a few of commonly used contrast enhancement methods including histogram equalization (HE), contrast limited adaptive histogram equalization (CLAHE) [2], brightness preserving bi-histogram equalization (BBHE) [3], and a robust image contrast enhancement (RICE) [5].

The experiments are performed to evaluate if the algorithms can effectively enhance image contrast and prevent over-enhancement. As shown in Fig. 5 (b) and (d), images processed by HE and BBHE are over-enhanced and visually unpleasant. CLAHE adds visible distortion, Its enhanced image in Fig. 5 (c) contains artifacts. Fig. 5 (e) shows that RICE can effectively suppress over-enhancement on images with higher image contrast. However, it performs poorly on low-contrast regions.

The proposed algorithm, as shown in Fig. 5 (f), produces the most visually pleasing results. It can effectively enhance image contrast while preventing over-enhancement. It also has robust performance on the input images with both hight contrast and low contrast.

C. Objective evaluation

The assessment of image quality is often subjective, however, proper quantitative measure is crucial for evaluating the performance of algorithms and obtaining the most ideal enhancement results. SDME is a quantitative measure effective in evaluating image enhancement [11], it is adopted to assess the experimental results in this paper.

The SDME is defined by the following equation [11]:

$$SDME = -\frac{1}{k_1 k_2} \sum_{l=1}^{k_1} \sum_{k=1}^{k_2} 20ln \left| \frac{I_{max,k,l} - 2I_{center,k,l} + I_{min,k,l}}{I_{max,k,l} + 2I_{center,k,l} + I_{min,k,l}} \right| \tag{8}$$

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

Fig. 5: Image enhancement using different methods. (a) Original images, (b) HE, (c) CLAHE, (d) BBHE, (e) RICE, (f) the proposed method.

where the image is divided into sub-blocks of size $k_1 \times k_2$, $I_{center,k,l}$ denotes the center value of each block, $I_{max,k,l}$ and $I_{min,k,l}$ are the local maximum and minimum value of each block respectively. A higher SDME value indicates better enhancement performance. In this paper, the sub-block size is set to 3×3.

Table 2 shows the SDME values of the experimental results. Consistent with what we observed in Fig. 5, the evaluation results suggest that the proposed method has the best enhancement performance.

TABLE II: SDME evaluation

Image	kodim07	kodim12	Cabin	Map
Original	119.6460	125.0094	92.9702	66.2138
HE	86.7316	89.7900	75.9337	69.8751
CLAHE	99.8771	86.9905	99.9597	85.1956
BBHE	90.7395	94.6149	91.2349	66.3967
RICE	120.8476	121.5501	102.4678	67.0107
Proposed Method	**125.8267**	**131.7553**	**117.1485**	**92.9666**

V. Conclusion

Conventional image contrast enhancement algorithms often suffer from the drawback of excessive enhancement. In this work, we have proposed an image contrast enhancement algorithm combining PLIP operations with a histogram modification framework. Experimental results showed that the proposed algorithm can effectively enhance image contrast while preventing over-enhancement. Objective measure adopted in this paper has also confirmed that the proposed method has better performance than several existing contrast enhancement methods.

Acknowledgment

This work was supported in part by the Macau Science and Technology Development Fund under Grant FDCT/106/2013/A3 and by the Research Committee at University of Macau under Grants MYRG2014-00003-FST and MYRG2016-00123-FST.

References

[1] R. C. Gonzalez and R. E.Woods, *Digital Image Processing, 3rd ed.*, Prentice Hall, Englewood Cliffs, NJ, 2007.

[2] S. M. Pizer, E. P. Amburn, J. D. Austin, R. Cromartie, A. Geselowitz, T. Greer, B. ter Haar Romeny, J. B. Zimmerman, and K. Zuiderveld, "Adaptive histogram equalization and its variations," *Comput. Vis. Graph.*, vol. 39, pp. 355–368, 1987.

[3] Y.-T. Kim, "Contrast enhancement using brightness preserving bihistogram equalization," *IEEE Trans. Consum. Electron.*, vol. 43, no. 1, pp. 1–8, Feb. 1997.

[4] Y. Wang, Q. Chen, and B. Zhang, "Image enhancement based on equal area dualistic sub-image histogram equalization method," *EEE Trans. Consum. Electron.*, vol. 45, no. 1, pp. 6875, Feb. 1999.

[5] K. Gu, G. Zhai, X. Yang, W. Zhang, and C. W. Chen, "Automatic contrast enhancement technology with saliency preservation," *IEEE Trans. Circuits Syst. Video Technol*, vol. 25, no. 9, pp. 1480 – 1494, Sep. 2015.

[6] M. Jourlin and J. Pinoli, "A model for logarithmic image processing," *J. Microsc.*, vol. 149, pp. 21–35, 1988.

[7] M. Jourlin, M. Jourlin, and J. C. Pinoli, "Image dynamic range enhancement and stabilization in the context of the logarithmic image processing model," *Signal Process*, vol. 41, no. 2, pp. 225–237, 1995.

[8] M. Jourlin, J. C. Pinoli, and R. Zeboudj, "Contrast definition and contour detection for logarithmic images," *J. Microsc.*, vol. 156, pp. 33–40, 1989.

[9] K. Panetta, S. Agaian, Yicong Zhou, and E.J. Wharton, "Parameterized logarithmic framework for image enhancement," *IEEE Trans. Syst., Man, Cybern. B, Cybern.*, vol. 41, no. 2, pp. 460–473, 2011.

[10] K. Gu, G. Zhai, M. Liu, X. Min, X. Yang, and W. Zhang, "Brightness preserving video contrast enhancement using s-shaped transfer function," in *Proc. IEEE Int. Conf. Vis. Commun. Image Process.*, 2013, p. 16.

[11] K. Panetta, Y. Zhou, S. Agaian, and H. Jia, "Nonlinear unsharp masking for mammogram enhancement," *IEEE Transactions on Information Technology in Biomedicine*, vol. 15, no. 6, pp. 918–928, Nov. 2011.