Low-Pass Filtering Aiming at Noise Generated in a Contrast Enhancement

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***Abstract*—In this paper, we propose a low-pass filtering process aiming at removing noise and artifacts generated by histogram equalization, while preserving the image signal variations. The filtering is made to provide different levels of smoothing strength by means of cascading stages of simple low-pass filters. A weak smoothing given by the first stage is applied to all the pixels, including those in edge regions, and the pixels located in the flattest regions are processed successively by all the filtering stages to get the strongest smoothing. A binary mask is used in each stage, except the first one, in order to shield pixels in non-homogeneous regions from over-smoothing. Simple algorithms are developed to generate the masks from the input image. The results of the simulation demonstrated that the proposed filtering leads to a good quality of the contrast enhancement in varieties of images and requires a low computation complexity.**

I. INTRODUCTION

A process of histogram equalization (HE) is often used to enhance the image contrast. However, the enhancement is not ideal as it may also enhance the noise and create artifacts in the image, affecting the image quality, particularly in homogeneous regions. One of the approaches to solving this problem is to make the transformation function adaptive. The contrast limited adaptive histogram equalization (CLAHE) [1] is one of the most commonly used adaptive HEs, in which the clip limit can be used to get a trade-off between contrast enhancement and noise generation. If a strong enhancement is performed, the noise created in the process can be very pronounced.

Another approach to a low-noise HE-base contrast enhancement is to use a low-pass filter to remove the noise generated by the histogram equalization. In [2], a multi-step binomial filtering is incorporated into the contrast enhancement. In the algorithm presented in [3], the pixel signals of an HE-enhanced image are processed iteratively by a transportation map regularization (TMR) filter. As the degree of noise contamination is different from region to region, a good filtering should be adaptive to the noise conditions of the regions.

The work presented in this paper is the development of a discriminative low-pass filtering process targeting the noise and artifacts generated in HE-based contrast enhancement. This filtering process is to apply different low-pass operations to pixels located in different regions for an effective noise removal and good edge preservation. The low-pass operations are controlled by the binary masks generated from the input image.

II. DESCRIPTION OF THE LOW-PASS FILTERING PROCESS

A. *Basic structure*

The basic scheme of the contrast enhancement involving the proposed low-pass filtering process is illustrated in Fig. 1. Low-pass filtering is used to remove the noise and artifacts created in the HE. In this scheme, I_i denotes the input image, I_C the image obtained after the histogram equalization, and I_o the output image. The challenging issue of the work is to make the filtering discriminative to noise and signal variations. The discrimination is in the two aspects.

- *In the image I_C*. The level of noise and artifacts created by the histogram equalization is different from region to region. The more homogeneous the regions, the more pronounced the noise. Thus, the pixels need to be processed differently. To do so, the pixels should be classified according to the contextual regions where they are located. The contextual regions are identified by the levels of homogeneity of the input pixel signals.
- *In the level of smoothing strength performed by the block of the low-pass filtering*. It should be able to provide different levels of smoothing strength to different groups of pixels. The strongest low-pass filtering is applied to the pixels located in the most homogeneous regions, and the weakest one to those in the least homogeneous regions in order to achieve the best edge preservation.

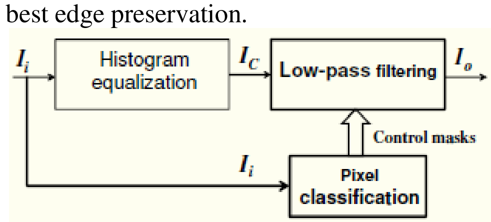


Fig. 1. Block diagram of the contrast enhancement involving the proposed discriminative low-pass filtering.

Taking the above-mentioned discriminative features into consideration, we propose a low-pass filtering process illustrated in Fig. 2. In this process, the filtering is performed by cascading stages of simple low-pass filters. If each filter is made to perform a modest smoothing operation, the level of smoothing strength applied to a group of pixel in the image depends on the number of successive low-pass operations performed on them. The first stage, referred to as the pre-filter, is to perform a very modest low-pass operation to all the pixels and thus no mask is applied. The low-pass operation of the succeeding stage, namely LP_1 as shown in Fig. 2, is performed while the pixels in the non-homogeneous regions are shielded by $Mask_1$. While the low-pass operations are being performed successively, the smoothing strength increases and the number of shielded pixels also increases. The strongest smoothing is applied to the pixels that remain exposed to all the successive low-pass operations.

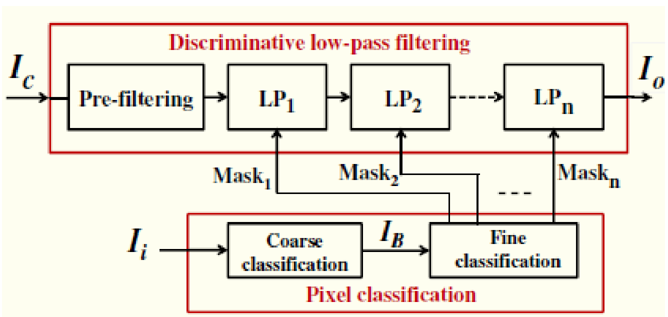


Fig. 2. Block diagram of the proposed low-pass filtering process, where I_i is the input image and I_C is the image obtained after the histogram equalization.

If the input image is divided into three region groups, i.e., obviously-homogeneous regions, obviously-nonhomogeneous regions, where a lot of edges are located, and the remaining regions, one will need three low-pass stages to perform the proposed discriminative filtering, i.e., the pre-filtering applied to all the pixels, LP_1 to those in the first and third groups and LP_2 to the first group only. The third group can be further divided to make the filtering process more precise, which requires more filter stages and more masks. The masks are generated by the block of pixel classification described in the following sub-section.

B. Pixel Classification

Each mask used in the proposed filtering process shown in Fig. 2 is a binary image, in which the pixel positions shielded from a low-pass operation has a status of logic-0. A mask that shields no pixel position would have the logic-1 status everywhere in its space, which is equivalent to no control mask, i.e., the case of the pre-filtering.

As shown in Figs. 1 and 2, the masks are generated from the original input image I_i, and pixel classification is done in two steps, coarse and fine classifications. The coarse classification is done by a gray level thresholding in the image histogram. It divides coarsely the pixels into two groups, creating a binary image I_B from the gray level image I_i. The second step is to identify the pixels misclassified in the first step, to correct their status and to generate the masks.

The histogram of an image, such as one illustrated in Fig. 3, indicates the gray level distribution. A high peak in a histogram is likely formed by the pixels located in homogeneous regions, referred to as **homogeneous pixels**. In the example shown in Fig. 3, a majority of the pixels in the shaded area, defined by the thresholds G_1 and G_2, are homogeneous pixels. Thus, these pixels are put in the group of homogeneous pixels, and each of them is made to have the logic-1 status, while the other pixels have the logic-0 status.

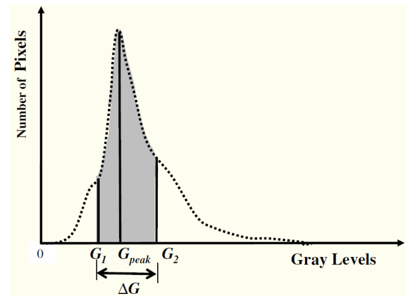


Fig. 3. Histogram of a low contrast image. Most of the pixels in the shaded area are likely from homogeneous regions and the majority pixels in the other parts, i.e., those not shaded, are from non-homogeneous regions.

The above-described classification by the thresholding is very coarse with the two kinds of misclassified pixels. Some of the pixels in the shaded area in the histogram shown in Fig. 3 are **non-homogeneous pixels**, i.e., pixels located in non-homogeneous regions, and they are mistaken as homogeneous pixels. Similarly, some pixels in the non-shaded area are homogeneous pixels and misclassified as non-homogeneous ones. Shifting each of the thresholds G_1 and G_2 toward G_{peak}, reducing $(G_2 - G_1)$, decreases the risk of misclassifying the true non-homogeneous pixels, as the density of the true non-homogeneous pixels is the lowest at G_{peak} level. But, such a shift would increase the non-shaded area and increase the number of homogeneous pixels in this area. These pixels are then mistaken as non-homogeneous ones. However, if the fine classification block is designed to correct the status of the misclassified homogeneous pixels, not that of the non-homogeneous pixels, $(G_2 - G_1)$ should be as small as possible to minimize the misclassification of the non-homogeneous pixels. Nevertheless, if $(G_2 - G_1)$ is made too small, the number of misclassified homogeneous pixels will become too large and the identification of these pixels will be very difficult. The binary mask illustrated in Fig. 4(b) is obtained by an appropriate set of G_1 & G_2, and the patterns formed by black pixels (logic-0) are identifiable by their shapes. The mask shown in Fig. 4(c) is obtained by reducing $(G_2 - G_1)$. In this mask, the patterns in the initially homogeneous regions become hardly identifiable.

(a) (b) (c)

Fig. 4. (a) Original image, (b) binary mask produced with a set of G_1 and G_2, and (c) with a much reduced value of $(G_2 - G_1)$.

As mentioned previously, the first task in the step of fine classification is to identify the misclassified homogeneous pixels, i.e., the pixels truly located in homogeneous regions but mistaken as non-homogeneous ones, and correct their status of logic-0 to logic-1. A pixel of logic-0 appears in the binary image as a black dot. A true non-homogeneous region formed by pixels carrying gray level variations and it needs to have a certain width and length to accommodate the variation. Thus, a narrow black line of one-pixel-width is very likely composed of misclassified homogeneous pixels. Some of such narrow lines can appear in a 3x3 window as the patterns, referred to as Category-1 patterns, shown in Fig. 5. The patterns in this category can be easily detected by examining the two conditions: (i) the center pixel is “0” and (ii) the number of “0”s (or the black dots) in the eight surrounding pixel positions is equal to or smaller than 2.

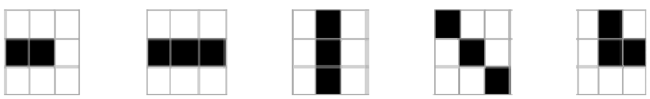


Fig. 5. Category-1 pattern samples. The other patterns in this category can be obtained by rotating, mirroring or shifting.

The patterns shown in Fig. 6 can also be considered as segments of one-pixel-width lines composed of misclassified homogeneous pixels. However, they look less isolated in a homogeneous region and are more likely located next to a larger black segment, i.e. a non-homogeneous region. In other words, the regions where such patterns are located are less obviously homogeneous than those of the Category-1 patterns, but it is unlikely that they are in non-homogeneous regions. This kind of patterns is referred to as Category-2 patterns. The detection of these patterns can be done by checking the three conditions: (1) the center pixel is “0”, (2) the number of “0”s in the 8 surrounding positions is equal to or smaller than 3, and (3) the Category-3 patterns shown in Fig. 7 are excluded.

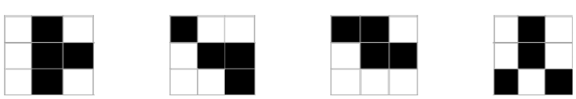


Fig. 6. Category-2 pattern samples.

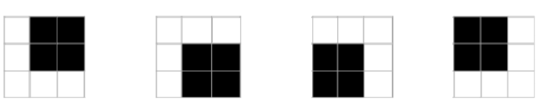
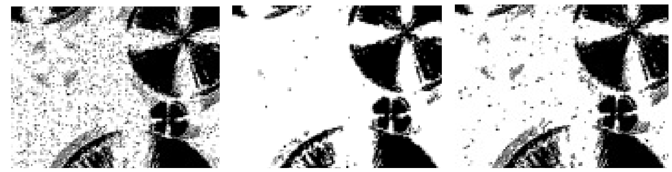


Fig. 7. Category-3 pattern samples.

Misclassified homogeneous pixels may also form patterns in which the center pixel in the 3x3 window is “0” and there are 4 “0”s distributed evenly in the eight surrounding pixel positions. They are referred to as Category-4 patterns and can be easily detected by simple logic functions.

In the example described in the last paragraph of Section 2A, the low-pass filtering process involves three stages and two masks are needed to control the operations in the second and third stages. The first mask is designed to shield the pixels located in the obvious-nonhomogeneous regions. It is generated from the binary image I_B, after the patterns of Category-1, Category-2 and Category-4 in I_B are detected and the status of the pixels forming these patterns changed. The second mask is to make the pixels in the obviously-homogeneous regions exposed and all the others shielded. It is also produced from I_B, by changing the status of the pixels involved in Category-1 patterns from “0” to “1”. Fig. 8 illustrates a binary image I_B and the masks generated in the step of the fine classification.



(a) (b) (c)

Fig. 8. (a) Binary image I_B obtained by the thresholding, (b) a mask shielding the pixels in obviously-nonhomogeneous regions, and (c) a mask exposing the pixels in the obviously-homogeneous regions.

III. PERFORMANE EVLUATION

The proposed low-pass filtering process is incorporated in the procedure of contrast enhancement shown in Fig. 1. Matlab simulation has been conducted to evaluate the quality of the enhancement with the proposed filtering. The CLAHE method is used to convert the input image I_i to I_C in which the gray level variations of the signals and noise are enhanced. In the filtering process, a 5x5 Gaussian filter with $\sigma = 0.5$ is used for the pre-filtering. It is followed by two bidirectional multi-stage median (BMM) filters [4] for the low-pass operations LP_1 and LP_2 shown in Fig. 2. The simulation results obtained by using the proposed filtering in the procedure are compared with those produced by the contrast enhancement involving the iterated TMR filtering performed after the histogram equalization [3].

The image shown in Fig. 9(a) is a low-contrast image of x-rays. The image contrast is enhanced by CLAHE, but the noise is also made more visible, particularly in the lower part of the enhanced image shown in Fig. 9(b). The images shown in Fig. 9 (c) and (d) are produced from that of Fig. 9(b) by applying the TMR filtering and the proposed one, respectively. One can observe that in the two images, the noise is significantly reduced. In the image shown in Fig. 9(d), the signal variations are visibly better preserved. For example, fine details in the central spine are clearly shown in Fig. 9(d).

The input image “Window and Desk” shown in Fig. 10(a) has interior and exterior scenes, and the signal gradients in high and low intensity levels are critically degraded. Some detailed image segments from those in Fig. 10 are shown in Fig. 11. In Fig. 11(b), the noise created by CLAHE is visible, for instance, above the pens located in the left-hand side, where there are a lot of gray level variations of image details. In the output image produced by the proposed filtering, the noise is reduced and the image details are well preserved.

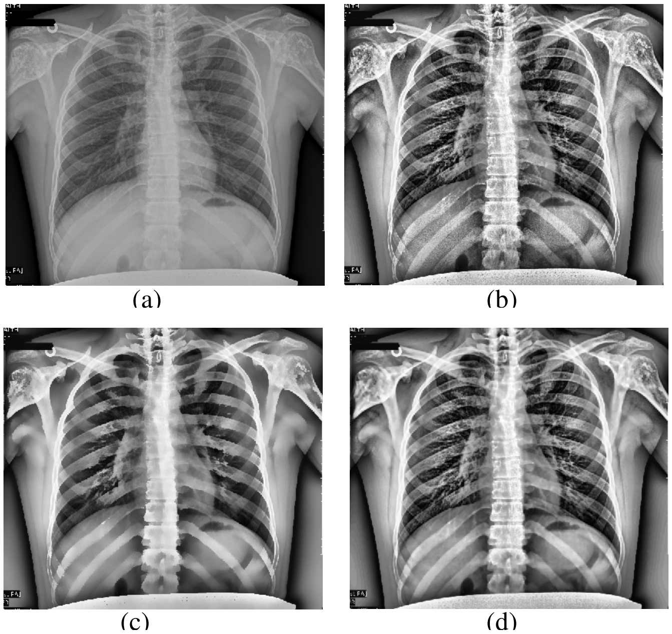


Fig. 9. (a) Input image of x-rays, (b) after processed by CLAHE, (c) by the iterated TMR [3], and (d) by the proposed low-pass filtering.

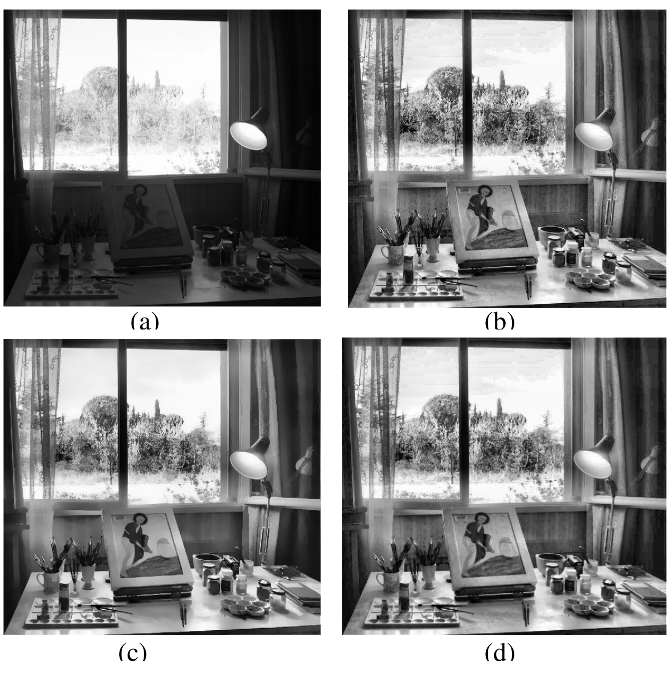


Fig. 10. (a) Input image acquired under over-and-under-exposure conditions, (b) after CLAHE, (c) by the iterated TMR [3], and (d) by the proposed low-pass filtering.

The amount of the computation for each of the filtering processes can be indicated by the elapsed time of the MATLAB simulation. Under the condition of the simulations performed with Intel Core 5i microprocessor @ 2.4GHz, the average elapsed time of ten runs for each of the two input image are presented in Table 1. It includes the computation time for the CLAHE. The data shown in this table demonstrate that the proposed filtering results in shorter computation time, i.e., smaller volume of computation for the process.

Table 1 Average elapsed time in second

Input image	Image size	with the TMR [3]	with the proposed one
X-rays	549 x 623	16.41	13.9
Window/desk	800 x 854	48.9	10.84

IV. CONCLUSION

In this paper, a low-pass filtering process is proposed targeting the noise and artifacts generated in a contrast enhancement by histogram equalization. In order to remove the noise effectively while preserving the signal variations, the low-pass filtering is made to have different levels of smoothing strength applied to different regions in the image. The filtering operations are performed by cascading stages of simple filters. Binary masks are generated from the input image and are used to control the filtering operations so that each of them is applied to selected groups of pixels. The simulation results show that the proposed filtering can effectively remove the noise and artifacts and preserve very well the image signals.

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REFERENCES

[1] S.M. Pizer, E.P. Amburn, J.D. Austin, R. Cromartie, A. Geselowitz, T. Greer, B.M. ter Haar Romeny, J.B. Zimmerman, and K. Zuiderveld, “Adaptive Histogram Equalization and its Variations,” *Computer Vision, Graphics and Image Processing*, vol. 39, 1987, pp. 355–368.

[2] F. Lamberti, B. Montrucchio, A. Sanna, "CMBFHE: a novel contrast enhancement technique based on cascaded multistep binomial filtering histogram equalization," *Consumer Electronics, IEEE Transactions on* , vol.52, no.3, pp.966-974, Aug. 2006.

[3] J. Rabin, J. Delon and Y. Gousseau, "Removing Artefacts from Color and Contrast modifications," *IEEE Transaction on Image* Processing, vol. 20, no. 11, pp. 3073-3085, 2011.

[4] A. Nieminen, P. Heinonen and Y. Neuvo, "A New Class of Detail-Preserving Filters for Image Processing," *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Vols. PAMI-9, no. 1, pp. 74-90, 1987.

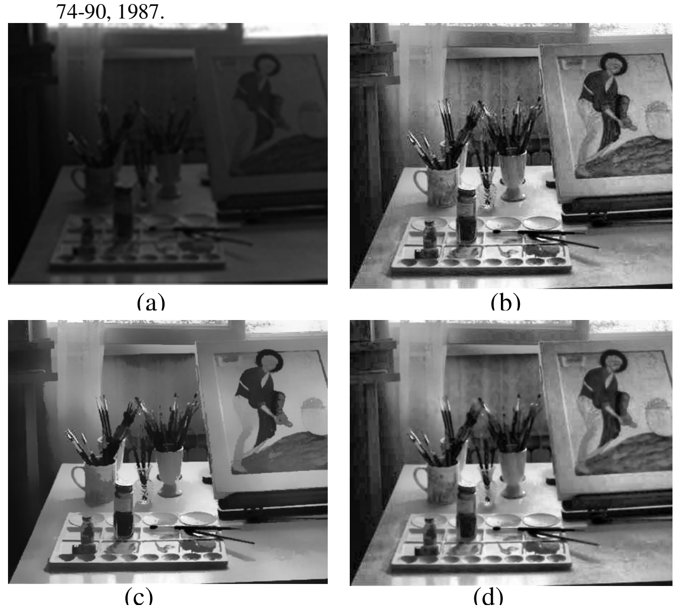

Fig. 11. Image details sampled from Fig. 10(a), (b), (c), and (d).