Entropic Contrast Enhancement

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Abstract—**A technique for the contrast enhancement of a picture is proposed. The method is derived from the entropy concept of the information theory. The originality of the algorithm rests on the use of a local contrast to define the digital entropy. The basic idea of the treatment is to enhance the contrast by transforming the global entropy. The same technique can also be used for an adaptive smoothing processing.**

I. Introduction

One of the basic questions in computer vision is how to retrieve the image aspects that allow the segmentation of the image into meaningful regions according to given features. In 2-D imagery, the basic feature is the gray level. For a given image, the gray-level distribution plainly informs about the image contrast and the existence of different density classes. These classes can be grouped together with respect to their density homogeneity and to their specific edges. However, it is often difficult to detect the edges between the different regions, especially in low-contrast images and in noisy images.

The image contrast is closely correlated to the gray-level gradient. High edge value corresponds to a change of local information or even global information. Hence, the local contrast can be enhanced by amplifying the edge values.

Many methods have been proposed to enhance the image contrast. Most of them are based on the gray-level histogram modifications [1]–[6]; some rest on a local contrast transformation [7]–[8] or on local edge analysis [9]–[10]. Many years ago, it had been established that the entropy is one of the quantitative measures of the digital information [1], [2], [11]. Since the first pioneer works of Frieden [12], the entropy concept is being widely and increasingly used as a powerful tool in image processing, namely, for the image reconstruction (Gull [13], Skilling [14], Burch [15],). Recently, Shiozaki [16] introduced an entropy operator useful for the edge extraction. As for us, the entropy concept has been used to design a novel procedure for the contrast enhancement.

One method to get an enhanced image contrast appeals to the histogram equalization, a well-known technique which, by the way, tends to equally distribute the image gray levels [2], [4], [5]. A uniform gray-level distribution, on the other hand, corresponds to high entropy value. Since the entropy and contrast are highly related to the gray-level distribution, then it was adequate to try to link them together. Subsequently, the contrast enhancement that leads to a better perception of the image structures, was shown by Dhawan *et al.* [8] to increase also the gray-level entropy.

As a matter of fact, we propose in the present paper an alternative approach consisting in the local contrast enhancement through an entropy amplification.

II. A New Contrast Enhancement Approach

The digital entropy for a given image is now concisely defined [1], [2]. Its one-dimensional measure H can then be written

$$H = -\Sigma P_i \operatorname{Log} P_i \tag{1}$$

where P_i is the probability function to find the gray-level i among n possible values. This definition is often used for gray-level thresholding [17], [18] and for edge extraction [16]. However, Ahmed [19] has recently used the two-dimensional entropy for gray-level thresholding and has given a comparison with the conventional one-dimensional entropy method.

To take into account the brightness in a region centered on the pixel (k, l), Shiozaki [16] makes use of the probability P_k defined as

$$P_k = g_k / \Sigma g_j \tag{2}$$

where g_k is the gray level of the pixel (k, l) and $g_j (j = 1, \cdots, J)$ the gray levels of neighboring pixels.

Since the contrast is highly related to the gray level gradient and the entropy to the brightness homogeneity, then it seems judicious to define a probability with respect to the contrast. The entropy will thus be directly connected to the contrast.

Indeed if one considers a window W_i centered on the pixel (k, l) of gray-level g_i, a local contrast can then be defined as

$$C_i = |g_i - g_i| / |g_i + g_i| \tag{3}$$

where g_i is either the average gray level associated with the window W_i, or better still the corresponding median gray level.

Then, by an analogy with Shiozaki (2), we define a probability associated with the local contrast C_i via the relation:

$$P_i = C_i / \Sigma C_k \tag{4}$$

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where C_k is the contrast associated with the pixel k belonging to the window W_i. The summation is performed over all the pixels belonging to W_i. P_i is obviously a probability and it satisfies the probability axioms $0 \leq P_i \leq 1$ and $\Sigma P_i = 1$.

Now, the entropy defined by (1) is related to the local contrast. It can be noticed that an increase of H denotes a high disorder and that low entropy means low disorder. The basic idea of this new approach of contrast enhancement is to increase the entropy and to assign to the given pixel the gray level associated with the new entropy value.

III. Contrast Enhancement Method

To transform the gray-level g_i into g_i', let us recall the entropy definition via (1), which can also be written as follows:

$$H = -P_i \operatorname{Log} P_i - \Sigma P_j \operatorname{Log} P_j. \qquad (5)$$

Now, to enhance the contrast, let us amplify the entropy, which leads to

$$H' = \alpha H \qquad (6)$$

with $\alpha > 1$. Furthermore, let us assume that the same amplification α which applies to the whole entropy also and similarly applies to each scalar pair of terms of the same rank. Then, in the summation, we get

$$\Sigma P_i' \operatorname{Log} P_i' = \alpha \Sigma P_i \operatorname{Log} P_i \qquad (7)$$

and for the pair i

$$P_i' \operatorname{Log} P_i' = \alpha P_i \operatorname{Log} P_i. \qquad (7\text{bis})$$

To transform the gray-level g_i into g_i', (7bis) is to be solved and P_i' is to be determined. As the equation has no obvious analytic solution, we have solved it numerically, using the simple and efficient method of Newton [20].

Once P_i' computed from (7bis), then the transformed contrast C_i' can be derived from relation

$$P_i' = C_i'/C_s'. \qquad (8)$$

It could be noticed that only the contrast of the central pixel is transformed. Thus, (8) can be written

$$P_i' = C_i'/(C_s - C_i + C_i'). \qquad (8\text{bis})$$

Where C_s' and C_s are, respectively, the sum of the transformed and of the original contrasts within the given window. Now C_i' can be computed from (8bis) since C_i, P_i, and P_i' are known

$$C_i' = P_i'(C_s - C_i)/(1 - P_i'). \qquad (9)$$

This transformed contrast must satisfy the condition $0 \leq C_i' \leq 1$, which leads to $0 \leq P_i' \leq 1/(1 + C_s - C_i)$. Obviously, this last condition is always satisfied as $C_s \geq C_i$. Furthermore, the maximum value of P_i' depends on the original contrasts and is

$$P_c' = 1/(1 + C_s + C_i). \qquad (10)$$

It corresponds to a critical value α_c for the magnification factor α which can be computed through (7bis) and (10):

$$\alpha_c = P_c' \operatorname{Log} P_c'/P_i \operatorname{Log} P_i. \qquad (11)$$

This means that for a given window one has to compute the critical value α_c in order to choose a magnification factor such that $\alpha \leq \alpha_c$ and then derive the corresponding P_i' and C_i'. Furthermore, one has to verify the condition $P_i' \leq 1/2$ as the function $P_i' \operatorname{Log} P_i'$ increases in [0, 0.5] and decreases in [0.5, 1]. After computing P_i', hence C_i', the original gray level is then transformed into g_i' by using the following expression:

$$g_i' = \bar{g}_i(1 \pm C_i')/(1 + C_i'). \qquad (12)$$

In contrast with the definition of Gordon [7] in which $\bar{g}_i$ is the average gray level of the neighboring pixels of (k, l), the median gray level is preferred herein to minimize the contour modifications [1], [2]. It can be noticed, through (3) and (12), that the median gray-level $\bar{g}_i$ is not modified by the process as the associated contrast is null. Then, the gray-level g_i is shifted apart from $\bar{g}_i$ according to the sign of the difference $(g_i - \bar{g}_i)$. More precisely, in order to preserve the contour location one needs to compute the mean edge gray level as $\bar{g}_i$ as done in [10], but the method is computationally involved since it requires the computation of the edge value for each pixel within the window. Gordon uses the average gray level but his solution noticeably modifies the contours as it will be shown. Using the median gray level constitutes a compromise between these approaches.

IV. Results and Discussion

The method was tested on low-contrast images obtained from thick sections (20 μm) of the olfactory bulb of a rat. The purpose was to point out the glomerules which are often difficult to distinguish from the background tissues [21], [22].

Fig. 1(a) is a digitized image of a longitudinal section. The central zone (a) is the so-called granular zone. The surrounding dark zone (b) is the plexiform layer. The next layer is the glomerular zone (c) externally followed by the nervous layer (d).

Fig. 1(b)–(d) are given for comparison. They have been obtained through the equalization technique [Fig. 1(b)] and using the Gordon method [Fig. 1(c), (d)]. Fig. 1(e) and (f) show the obtained results using our contrast enhancement technique on the original image.

As can be seen from Fig. 1(b), the equalization technique tends to abruptly enhance the global contrast, to smooth out small details (especially in the zone (a) and its periphery), to thicken the contours. The Gordon method has been tested using various window sizes (3×3; 9×9) and the square root function as contrast enhancement function. The large window size is less sensitive to the noise but it blurs the high and medium spatial frequency information (contours of zone (a) and of the glomerules). The small window size looks more sensitive to background noise and less sensitive to the medium frequency loss. The contours are thickened and the associ-

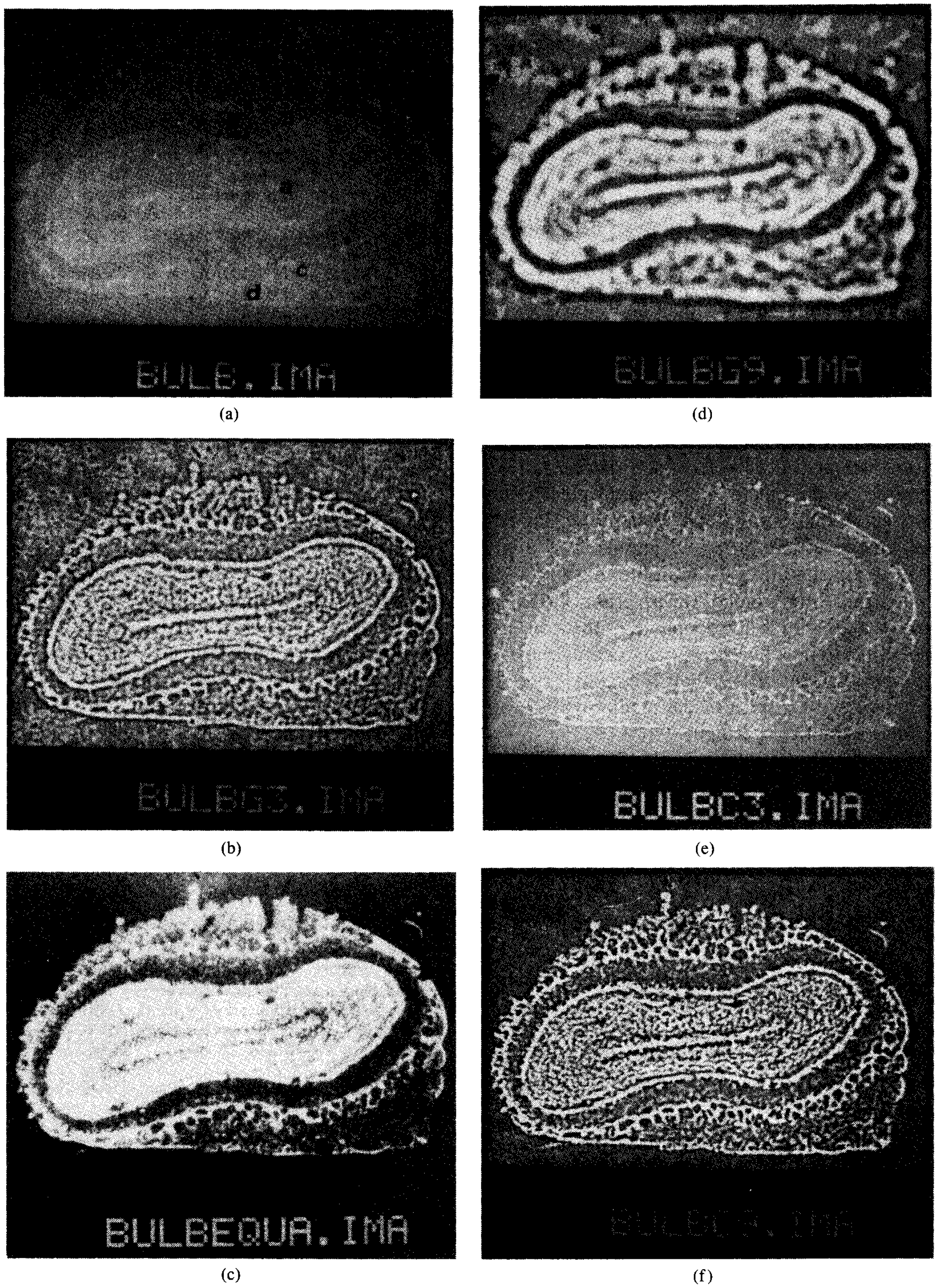

Fig. 1. (a) The digitized original image. (b) Image (a) after equalization. (c) and (d) Image (a) treated by Gordon method with 3×3 and 9×9 window size, respectively. (e) and (f) Image (a) treated by our method with 3×3 and 9×9 window size, respectively.

ated high frequencies are lost. Even for the smallest window size, a smoothing effect is observed which eliminates the small details.

The proposed method was used with the same window size. For the 3×3 window size, one observes:

- a slight contrast amplification, as compared to Fig. 1(c),
- the preservation of small details (contours of the zone (a), glomerules), and
- the nonamplification of the background noise.

Even for the 9×9 window size [Fig. 1(f)] the details are preserved: the superiority on the Gordon method is obvious from the comparison to Fig. 1(d); the superiority is observed also if one compares to the Fig. 1(c) as regards:

- the high frequency details of contour and
- the background noise.

Moreover it is to be noticed that increasing the window size does not imply a significant smoothing effect with our method. Whereas the Gordon method is limited in the window size, given the induced smoothing effect, multiple possibilities of image improvement are offered by our method.

V. Conclusion

We have investigated a new approach of contrast enhancement based on the image entropy concept. The obtained results show that the method works well. Indeed, the main advantage of the proposed approach is that it uses the local contrast to define the digital entropy. The basic idea is to transform a global information, the image entropy, as a function of a local quantity, the contrast. This method seems to be powerful for sharpening the contours. Furthermore, it preserves their locations since the contrast is defined with respect to the median gray level. The algorithm is easy to implement.

VI. Remark

It can be noticed that an adaptive filtering process is obtained when $\alpha < 1$ is used. Furthermore, for $\alpha << 1$, the treatment tends towards a median filter [24].

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