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Multi-scale contrast enhancement of oriented features in 2D images using directional morphology

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ABSTRACT

This paper presents a multi-scale contrast enhancement scheme for improving the visual quality of directional features present in 2D gray scale images. Directional morphological filters are employed to locate and extract the scale-specific image features with different orientations which are subsequently stored in a set of feature images. The final enhanced image is constructed by weighted combination of these feature images with the original image. While construction, the feature images corresponding to progressively smaller scales are made to have higher proportion of contribution through the use of progressively larger weights. The proposed method has been formulated, implemented and executed on a set of real 2D gray scale images with oriented features. The experimental results visually establish the efficacy of the method. The proposed method has been compared with other similar methods both on subjective and objective basis and the overall performance is found to be satisfactory.

1. Introduction

Digital images either captured or scanned may be of low contrast due to some obvious but undesirable factors like - poor illumination of the object, poor quality of the imaging device, lack of expertize of the operator etc. for captured images. Scanned images (for example- document images, fingerprint) on the other hand may suffer from the same problem due to inherent noise present in acquisition devices, aberrant condition of objects to be scanned or unwillingness of the individual. contrast enhancement, in a broader sense, is the technique for improving the images in measure of visual quality. there is as such no universal criterion or unifying theory for enhancing an image; it is a problem specific procedure [1]. accordingly, a number of approaches have been developed to meet this goal. all the existing methods for contrast enhancement can broadly be classified into two categories (*i*) global contrast enhancement [1,2] and (*ii*) local contrast enhancement [3–6]. Among several proposals, histogram modification techniques [7–12] are the most popular due to their straightforward and intuitive implementation qualities. Global techniques like histogram stretching or histogram equalization [13–15] modify the image through monotonic pixel mapping to transform a narrow histogram by spreading its gray level clusters over a dynamically suitable range. However, it is seen that a single global mapping may not be sufficient to enhance the local contrast efficiently and adequately. Consequently, the bi-histogram equalization [16] was proposed in which the global histogram is divided into two sections depending upon the mean intensity value. Furthermore, block based local histogram equalization technique has been proposed. Dorst [17] adapted histogram stretching method over a neighborhood around a candidate pixel for local contrast stretching. In addition to local statistics based contrast stretching technique, a number of proposals have been suggested on multi-scale [18–20] approach for enhancing image contrast. Since last few decades mathematical morphology [21,22] has been used for analysis of both binary and gray scale images. It is also used as a popular and powerful tool for image enhancement [23–27]. However, conventional morphological operations are found to be less efficient for the processing of images with oriented features. Therefore, directional morphology [28–31] has been introduced as a remedy to make the conventional morphological operations additionally more sensitive to a specific range of orientations. All the basic operations of mathematical morphology have been extended in respect of directional morphology. Van Herk [32] has proposed the directional erosion, dilation operations for gray scale images by considering only three fundamental directions - horizontal, vertical and diagonal. Soille et al. [30], on the other hand, have proposed a method that can be applied suitably on images having features oriented at arbitrary angular directions. Evidently, directional morphology has become more suitable and efficient tool for analyzing the images with oriented features [33–37]. In this paper we present a multi-scale contrast enhancement scheme employing directional morphology. Both the bright and dark orientation specific features are identified and extracted in each

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scale using directional morphology. The oriented features so extracted are combined to construct the feature images which are subsequently recombined with the original image in a way that serves the purpose of contrast enhancement. The proposed method has been implemented and executed on a set of real 2D gray scale images having prominent features that have arbitrary spatial orientation over the entirety of the respective images. Organization of the rest of the paper is as follows. After this introductory section we present a brief review of (a) mathematical morphology and (b) directional morphology in Section 2 along with related transformations. The proposed method is presented in Section 3. Section 4 presents the experimental results along with performance analyses. Finally concluding remarks are made in Section 5.

2. A brief review of tools used in the proposed algorithm

2.1. Directional morphology

In spite of having quite a good number of advantages, conventional morphological operations suffer from a number of drawbacks. For example, an isotropic SE is impartial to any directional or oriented features. Therefore, features which deserve to be isolated based on their specific orientation may not be detectable by using conventional morphological operations. To handle such problems, directional morphological operations were proposed by Soille et al. [30]. The response of the features is high if there is a reasonably good amount of matching between the orientation of the SE and that of the local feature or object. Considering the image pixels in discrete locations as square grids, the slope of a line with an arbitrary orientation θ can be defined as an irreducible fraction as:

$$\Delta y/\Delta x = \begin{cases} +ve & \text{when } 0^\circ < \theta < 90^\circ \\ -ve & \text{when } -90^\circ < \theta < 0^\circ \end{cases} \quad \text{where } \theta = \tan^{-1}(\Delta y/\Delta x) \tag{1}$$

Notably, 1/0 and 0/1 is considered as vertical and horizontal line respectively. Lines which are not oriented along the principal directions, namely horizontal, vertical and diagonal, can be represented uniquely by Bresenham line [38]. The number of different discrete line segments for a particular orientation can be calculated as:

$$k = \max(|\Delta x|, |\Delta y|) \tag{2}$$

These different line segments are generally used as the structuring elements (SE) in directional morphological operations. The length of each SE is measured as:

$$\lambda = nk \quad \text{for } n \geq 1 \tag{3}$$

The value of n indicates the number of points considered in the formation of periodic line [39,40] along a specific direction. Fig. 1 represents the periodic line and the set of possible discrete line segments.

A small neighborhood of a gray-scale image may contain more than one feature oriented along more than one direction. The objective would be to morphologically detect all such features simultaneously. With such views, the gross effect of erosion (dilation) at a pixel location (x,y) is estimated as the overall minimum (maximum) of all the eroded (dilated) components along all possible discrete orientations.

$$E_{tot} = \min(E_{\alpha_1}, E_{\alpha_2}, \ldots, E_{\alpha_n}) \tag{4}$$

In the above equation, α_i represents the structuring element along a specific orientation and E_{α_i} is the erosion along that direction. Similarly, directional opening (or closing) can be realized by combining the directional erosion (or dilation) and dilation (or erosion) in a sequential manner.

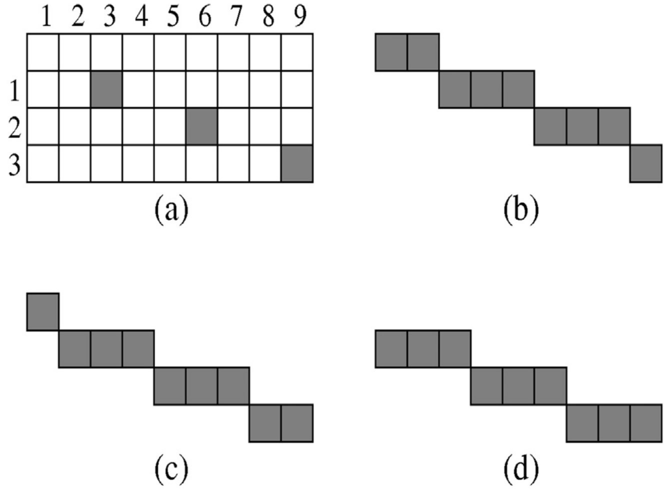

Fig. 1. (a) Showing the periodic line considering n=3, (b)–(d) representing all possible line segments, with slope (−1/3).

2.1.1. Translation invariant directional morphology (TIDM)

Although the directional morphology, discussed above, has established its efficiency in extracting features in arbitrary orientations, still it has some drawbacks. For example, the proper shape of any feature may be distorted after filtering with fundamental directional morphology. As the structuring elements acquire different shapes for a particular line with a fixed orientation, as shown in Fig. 1, the filtered image along that line yields different effects in shape. Therefore, a translation invariant approach of directional morphology has been introduced [39] by including the periodic line [40] as an SE as well. A periodic line with a given slope, depicted in Fig. 1(a), remains invariant with the pixel positions along its specific direction.

In TIDM approach, the set of linear structuring elements $L_{p,i,\theta}$ in any arbitrary angle θ can be decomposed into the periodic line $L_{p,\theta}$ and k possible line segments $L_{i,\theta}$ where $i = 1, 2, \ldots, k$. Mathematically

$$L_{p,i,\theta} = L_{p,\theta} \oplus L_{i,\theta} \quad \textit{for } i = \{1, 2, \ldots, k\} \tag{5}$$

Here $\oplus$ denotes dilation [41].

Translation invariant directional dilation δ and erosion ϵ can be formulated respectively as:

$$\delta_{L_{p,i,\theta}} = \delta_{L_{i,\theta}}(\delta_{L_{p,\theta}}) \tag{6}$$

$$\epsilon_{L_{p,i,\theta}} = \epsilon_{L_{i,\theta}}(\epsilon_{L_{p,\theta}}) \tag{7}$$

Opening of an image f(x,y) is calculated in TI directional morphology for a line component L_i as:

$$\chi_{L_{p,i,\theta}} = \delta_{L_{p,i,\theta}}\left(\epsilon_{L_{p,i,\theta}}\right) \tag{8}$$

In a similar fashion, TI directional closing can be implemented by altering the sequence of erosion and dilation of Eqn. (8) as given below:

$$\xi_{L_{p,i,\theta}} = \epsilon_{L_{p,i,\theta}}\left(\delta_{L_{p,i,\theta}}\right) \tag{9}$$