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Biomedical images enhancement based on the properties of morphological spectra

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ABSTRACT

The method enhancing distinctiveness of the micro-morphological structures, developed using the properties of morphological spectra of their monochromatic 2D images, is presented and its effects on the bone section image are statistically compared with enhancements by Sobel, Roberts and Laplace high-pass filters. Comparison of different filters based on statistical parameters of the classes of selected image details is presented. The preferable method for choosing filtering weight coefficients is described and illustrated by an example of processing an electron-microscope image of a biotechnological specimen. The applicability of this approach and possible development directions are discussed.

1. Introduction

Since the medical imaging systems supplied with computer-aided image analyzing tools allow images enhancement, recognition and evaluation of specific details and parameters, they are having a substantial role in modern medical diagnosis. However, the detection of objects of unknown shape and size, as in detection of tumors of internal organs or cerebral stroke diagnosis is still lacking and development of more accurate and effective methods of image segmentation are needed.

In specific case of tumor and stroke diagnosis the detection of lesion is based on discrimination between normal and ill tissues manifested by differences of their brightness, color, and/or of specific structural (micro-morphological) features. The sets of visual features and their characteristics allowing discrimination, localization and possibly delineation of abnormal tissue, named *biomedical textures*, due to their irregularity, can be considered as instances of chaotic or of random 2D structures [1–3] and statistical tools can be applied in their analyses. Therefore, quality enhancing image filtering should aim at emphasizing the differences between statistical parameters of the discriminated textures or increase the *distinctiveness* (contrast and contours) of the details that are analyzed.

Subsequently to image enhancement the parameters crucial for medical diagnosis of lesion are extracted during

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image segmentation. The efficiency of image segmentation depends on proper algorithms for determining adequate texture parameters that are suitable to discriminate the relevant classes of textures, and multiple approaches based on different image characteristics to establish these algorithms were described in literature (for example on color or luminance level in [4,5]; 2D Fourier spectra or wavelets in [6–10]; random Markov fields or co-occurrence matrices in [11,12] and fractal dimensions methods in [13]).

Two basic classes of image enhancement algorithms and procedures are described in the literature [2,7,9]: (a) low-pass procedures reducing the additive noise level and (b) high-pass procedures enhancing visibility of small spots, blobs, contours and/or edges. For image segmentation and final specific details selection the image enhancement procedures are usually combined with non-linear thresholding operations. Typical example of such image enhancement procedure is the Canny image enhancement algorithm [14] being a combination of: Gaussian noise smoothing filter, linear Sobel high-pass filter, narrowing and thresholding operations. However, not all contouring methods with thresholding operations can effectively be combined. This is caused by the fact that sensitive contouring procedures (like, e.g. the Lindeberg algorithms [15]) produce a large number of artifacts in the form of superfluous separate line segments. In such case a decision, which of them represent non-closed contours of the objects of interest, becomes an additional problem. Moreover, the problem is additionally complicated if blurred and by additional noise affected images are to be processed. The low-pass (smoothing) and high-pass (differentiating, contouring, etc.) image filtering operations are contradicting each other and choosing a compromise between them needs a careful examination of filter properties. On the other hand, in some medical and technological applications blurred and by noise affected details in the examined images should be detected, counted, measured and classified with desired accuracy. The results of advanced biomedical and/or technological image processing depend both on the carefulness of the corresponding specimen preparation and on the effectiveness of strongly defined image enhancement algorithms. Otherwise, the results of experiments become far from reality and mutually incomparable.

This study elaborates biomedical images filtering methods based on the properties of *morphological spectra* (*MS*). The *MS*-based approach, in which morphological spectra matrices of components of 2D monochromatic images expansion into the series of 2D orthogonal functions are defined as adequately coded discrete counterpart of Walsh functions [16,17] in a specific hierarchical form, employs a decomposition of original image into a set of sub-images corresponding to the spectral components of fixed levels. The concept of *MS* and their application to description of textures in biomedical image analysis was introduced in [18], the formal properties of this approach were described in details in [18,19] and their application to linear image filtering was presented in [20]. Moreover, recently designed software *IASS* and *USGstat* [21] allowed effective *MS* calculations and more advanced experiments on *MS* application to biomedical images filtering.

Below, blurred and low-noise biomedical image processing methods are considered. In this case image enhancement consisting in improving the distinctiveness of variously sized details and forms in order to facilitate their mutual separation from each other is required. Since, the standardized method to assess the enhancement level for this type of images is not established in literature, it is acceptable that visual expert assessment of the difference between the original and the filtered image, based on individual image quality criteria, is widely used. However, such approach seems not appropriate, if image enhancement is a preliminary step to computer-aided image analysis.

This work presents: (1) effects of employing *MS*-based high-pass filters to improve distinctiveness in a wide class of biomedical images by comparison with analogous results obtained by using three alternative (Sobel, Laplace and Canny) types of image enhancement filters; (2) an approach and an example based on statistical comparison of filters enhancing image distinctiveness; and (3) a method and an example of a *MS*-based filter's coefficients selection for effective discrimination of textures. Moreover, this work presents novel concepts and methods concerning *MS* application to enhance the distinctiveness of biomedical images.

In Section 2 basic notions concerning the *MS* of 2D images are reminded and the principles of *MS*-based image filtering are described. Section 3 contains relevant results of this study. The examples in this section include typical noiseless biomedical images enhancement by *MS* based approach. The effects of image transformation achieved by Sobel, Laplace and Canny high-pass filtering are compared with those obtained by the *MS*-based filtering method (Example 1). The filtering effectiveness in four types (Sobel, Roberts, Laplace and *MS*-based) of filters is assessed by comparing statistics of spots discriminated in the image of a bone section (Example 2). Section 3 includes a description of a novel approach to select *MS* filtering weights coefficients that improve discrimination of selected textures in some biotechnological images (Example 3). Section 4 contains conclusions concerning practical applicability of *MS*-based biomedical image enhancement methods.

2. Introduction to *MS*-based image filtering

2.1. Principles of morphological spectra

The discrete 2D monochromatic images can be considered in a form of bitmaps:

$$\boldsymbol{u} = [u_{i,j}], \quad i \in [1, \ldots, I],\ j \in [1, \ldots, J], \tag{1}$$

where $u_{i,j}$ are pixel values, $u_{i,j} \in [0,\ldots,K-1]$, I is the number of rows, J is the number of columns, K is the number of brightness levels ($u_{i,j} = 0$ corresponds to *black*). It is assumed that 2 is a minimum value of I, J and K. The calculation of *MS* of a given image requires the bitmap $\boldsymbol{u}$ to be divided into *basic windows*. In order to define and localize *basic windows* their size $2^n \times 2^n$ should be established in the following manner. Let c be a natural number such that $2^c \leq C < 2^{c+1}$ where $C = min(I,J)$; then for $0 \leq n \leq c$ the nth level morphological spectra $\mathbf{V}^{(n)}$ for $\boldsymbol{u}$ can be calculated. According to the definition, $\mathbf{V}^{(0)} \equiv \boldsymbol{u}$ and higher-level *MS* can be defined. For any fixed $n > 0$ $\mathbf{V}^{(n)}$ is a set of $h = 4^n$ real matrices called *spectral components*. Any single nth