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Quantitative tests-based assessment of biomedical image enhancement procedures

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ABSTRACT

This paper describes a novel method of images enhancement procedures evaluation. A necessity of such method follows from the fact that the results of morphological or statistical image analysis in medical and/or technological applications strongly depend on the effectiveness of image preprocessing. The proposed method is based on standard images called testing sets composed of several basic patterns. Filtered testing sets are compared to basic patterns and the averaged distances between them are used as primary filtering quality scores. Then, they are used to calculation of several secondary parameters called image restoration errors. The image restoration errors make possible separate characterization of filters' ability to improve image contrast, discrimination of small details or neglect the influence of image parallel shifts on the visibility of image details. Practical application of the proposed method is illustrated by example of comparison of the quality of three exemplary filters: a one based on second-level morphological spectra, Laplace and Sobel, filters. Similar comparison has been performed on the same filters combined with image binary thresholding procedures. At last, the numerical evaluation is compared to visual filters evaluation based on the results of NMR brain image enhancement reached by using different filtering methods.

1. Introduction

Computer-aided image analysis plays a significant role in biomedical research works as well as in modern medical diagnosis. The images subjected to analysis very often are distorted and some preliminary operations for their improvement are needed. Typical operations of this sort consist in reduction of additive noise level, removing the artifacts, enhancement of contrast and strengthening contours of the visualized objects [1–5]. For this purpose various methods based on linear or nonlinear image filtering and more sophisticated logical operations have been elaborated [1–8]. In practice, image enhancement computer procedures combining various methods are used. However, noise reduction and contrast or contours enhancement are in some sense opposite aims. Noise reduction consists in damping down high spatial frequency image components while small image

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details visualization needs reinforcement of those components. Moreover, image deterioration caused by noise and that caused by blurring are, in fact, governed by two different physical mechanisms. The first one is caused by superposition of noise on an original image and the signal-to-noise ratio is a satisfactory measure of the resulting image quality. The second one is caused by undesired transformation of original image. In this case, the resulting image quality does not depend on the original image intensity, because the image deterioration effect is of multiplicative rather than of additive type. However, when talking about image enhancement three types of images should be taken into consideration: I – an "ideal" image of a conjectural real object, II – really available image (noisy, blurred, distorted, etc.), III – image II enhanced by a filtering procedure. For the purposes image visual perception improving a comparison of distances between the II and III types of images is usually taken into consideration. In such case, various distance measures (Manhattan, root-mean-square, peak signal-to-noise ratio, etc.) can be used, as shown in [4,5]. The situation becomes different if image enhancement is aimed at improving the quality of numerical analysis of some, fuzzy by nature, natural objects. An original form of objects in blurred biomedical images is neither a priori known nor strongly defined (e.g. no "real" contour of a stain in water exists because it depends on color discrimination level. Similarly the contours of cells in a microscopic biological specimen can be partially invisible). Nevertheless, for diagnostic or control purposes we try to detect blurred objects and to evaluate their geometrical, morphological and/or statistical parameters by preliminary using less or more sophisticated image enhancement procedures. However, up to now, no exact assessment method of the effectiveness of image distinctiveness enhancing procedures is commonly used. Instead, in practice, the image enhancement procedures are assessed by visual examination and comparison of the enhanced (filtered) and the deteriorated images, while they rather with some non-deteriorated, "ideal" patterns should be compared. A review of various approaches to numerical evaluation of image quality is given in [4,9]. Until the enhanced images at the next step of their processing are subjected to a visual qualitative examination, the problem seems to be of low importance. Otherwise, if they are to be more exactly (morphologically, statistically, etc.) examined, the image enhancing procedures should be more strongly controlled in order to reduce the influence of subjective assessment on the measured parameters. That is why in [10] a method of image enhancing procedures evaluation based on statistical parameters drawn from selected natural images was proposed. However, such approach is strongly connected with a type of natural images used as a sort of standards. In such images small and large, low- and high-contrast details co-exist and based on them total image assessment mix various image quality aspects. Moreover, the rates of various forms of image details in different natural images are specific and based on them image quality assessment are mutually incomparable; e.g., an effective bone-section image enhancement filter may occur ineffective for enhancing the procedures of calcifications detection in radiological breast images, etc. In this paper an approach to image enhancing procedures assessment based on standard numerical tests is presented. The tests are given as a collection of artificial image bitmaps of some basic visual patterns. This makes us able to numerically assess the enhancement power of a procedure separately, for three basic shapes, four scales and eight contrast levels, as well as to calculate several total image enhancement characteristics. A preliminary version of this approach was presented in [11]. Below, it is presented in a more developed form and the results of using it to image filtering procedures improvement are illustrated by two biomedical examples. It also is shown that image contours reinforcement and image distinctiveness enhancement are two different tasks and in general different procedures should be used for reaching those goals. This is caused by the fact that effective image contours reinforcing procedures usually produce a lot of apparent details not corresponding to real small objects. The below-presented tests suits to the assessment of monochromatic low-contrast various scale noiseless image enhancement procedures. Tests for assessment of the procedures of other classes of images enhancement are going to be presented in a forthcoming paper. The paper is organized as follows. The principles of construction of standard visual patterns are described in Section 2. Section 3 presents proposals for numerical scores evaluating the quality of image enhancement procedures. In Section 4 materials (tested image enhancement procedures) used in experiments are described. In this section a numerical example illustrates the test-based numerical method of several image enhancement procedures assessment and comparison. The method of using testing sets to image enhancement procedures assessment (including a case of NMR brain image and a radiological breast image enhancement) are by next two examples presented in Section 5. Section 6 summarizes the results of experiments, contains conclusions and suggestions concerning further development of the proposed method.

2. Construction of standard visual patterns

There will be considered the tests for numerical multi-aspect evaluation of the effectiveness of images enhancement procedures. Considerations are limited to monochromatic (gray scale) image enhancement procedures, typical in biological, biomedical, technological, etc. investigations. It is assumed that the enhancement procedures are aimed at preparing the images to be visually examined or analyzed from the point of view of their structural, morphological or statistical properties. Moreover, it is assumed that the images carrying information about the properties of some real objects have been subjected to various types of deformations and/or distortions and the aim of their enhancement consists in restoring the distinctiveness of the details being of interest for the users. Till now, for this purpose, various types of exemplary testing images, like "Lena", "baboon", "paprika" etc. are widely used [12]. They do not exactly suit to testing the procedures of enhancement real biomedical images, like those shown in Fig. 1.

The specificity of biomedical images consists in variety of size and form of the image details under examination, their fuzziness, non-homogeneity of luminance and contrast levels, existence of image acquisition artifacts, etc. The image