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A Logarithmic-like Image Processing Framework for Biomedical Image Enhancement

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Abstract – It has been widely acknowledged that Logarithmic Image Processing (LIP) models offer a new approach for image enhancement. In this paper, we compare the existing LIP models to a new, logarithmic-like model, by means of a modified contrast stretching method. The proposed approach exhibits significant improvements regarding the overall contrast and details visibility over a large set of biomedical applications.

Keywords: Logarithmic image processing model, contrast enhancement, biomedical image processing.

I. INTRODUCTION

Given the wide range of details of interest in biomedical images and its wide potential areas of impact, it is desirable to develop new efficient techniques for image enhancement [1], [2]. Even though significant advances occurred in biomedical imaging over the past few decades, there are still remaining challenges and directions for enhancement algorithms such as image features contrast, detail visibility or background noise removal.

The aim of this paper is to introduce a new logarithmic-like image processing (LLIP) framework and show its usage for biomedical image enhancement. The remainder of the paper is organized as follows: Section II will briefly describe the existing LIP models and the proposed model. In section III, we present a LIP-based image enhancement method derived from the classical contrast stretching. Sections IV and V present experimental results and conclusions.

II. LOGARITHMIC IMAGE PROCESSING MODELS

The underlying physical properties of the imaging system used in biomedical applications are, most of the time, naturally multiplicative. (For instance, in the case of an X-ray image, the image values represent the transparency/ opacity of the real objects imaged by any given pixel.) The key to the logarithmic image processing (LIP) approaches is a homomorphism that transforms the product into a sum (by logarithm), allowing the use of the classical linear filtering in the presence of additive components. Also, it should be clear that the functions we use are bounded (say, they take values in a bounded interval *[0, M)*). During the image processing, the following problem may appear: the mathematical operations on real valued functions use implicitly the algebra of the real numbers i.e. on the whole real axis and we are faced with results that do not belong anymore to the interval *[0, M]* - the only ones with physical meaning. Such an approach was discussed for instance in [3] for X-ray image enhancement or in [4] for the creation of high dynamic range images by bracketing.

To our best knowledge, only two LIP models have been proposed so far. The first model has been introduced by Jourlin and Pinoli in the mid-80s (that we will subsequently call the ”classical” model [5], [6]); a more recent model has been proposed by Pătraşcu [7], [8] (that we will subsequently call the ”homomorphic” model).

A. *The classical LIP Model*

Within the classical LIP model, the intensity of an image is modeled by its gray tone function [5], defined in the bounded interval *[0, M)*, with *M* being a strictly positive constant. The addition, the subtraction of two gray tone functions **x** and **y** and the multiplication of **x** by a real number α are defined as:

$$x \oplus y = x + y - \frac{x \cdot y}{M} \tag{1}$$

$$x \Theta y = M \cdot \frac{x - y}{M - y},\ x \geq y \tag{2}$$

$$\alpha \otimes x = M - M(1 - \frac{f}{M})^{\alpha} \tag{3}$$

B. *The homomorphic LIP model*

The logarithmic model proposed by Pătraşcu in [7] works with bounded real sets: the gray–tone values of the involved images, defined in [0,*M*), is linearly

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applied onto the standard set *(−1, 1)*. The addition, the subtraction of two gray tone functions *x* and *y*, and the multiplication of the gray tone *x* by a real number α are defined in terms of the usual (real scalar) operations as:

$$x \oplus y = 1 - \frac{(1-x)\cdot(1-y)}{1+x\cdot y} \tag{4}$$

$$x \Theta y = \frac{x-y}{1-x\cdot y} \tag{5}$$

$$\alpha \otimes x = \frac{1-\left(\frac{1-x}{1+x}\right)^{\alpha}}{1+\left(\frac{1-x}{1+x}\right)^{\alpha}} \tag{7}$$

C. *The proposed LIP-like model*

In the proposed LIP-like model the gray–tone values defined in [*0,M*) are linearly mapped to the standard range [0,1]. The addition, the subtraction of two gray tone functions *x* and *y*, and the multiplication of the gray tone *x* by a real number α are defined in terms of the usual (real scalar) operations as:

$$x \oplus y = 1 - \frac{(1-x)\cdot(1-y)}{1-x\cdot y} \tag{8}$$

$$x \Theta y = \frac{x-y}{1+x\cdot y-2\cdot y}, \quad x \ge y \tag{9}$$

$$\alpha \otimes x = \frac{\alpha\cdot x}{1+(\alpha-1)\cdot x} \tag{10}$$

III. MODIFIED CONTRAST STRETCHING IMAGE ENHANCEMENT

Contrast stretching (normalization) is a simple image enhancement technique that attempts to improve the contrast in an image by expanding the range of intensity values it contains to span the full range of values. The main idea behind contrast stretching is to increase the dynamic range of intensities in the processed image [2]. In our study, we will develop the simple contrast-stretching operation defined in the LLIP framework as:

$$y = (x \Theta m) \otimes \alpha \tag{11}$$

where *x* represents a pixel value within the original image, *y* is the transformed pixel value, *m* is the minimum value within the original image and α is the amplification factor (a scalar constant). The gray tone operations are performed as given by the proposed model (equations (8) – (10)). Denoting the image value range (the difference between the maximum and the minimum value within the image) by K, one must obviously choose α such that

$$K \otimes \alpha = \frac{\alpha\cdot K}{1+(\alpha-1)\cdot K} = 1 \tag{12}$$

As one can easily see, α cannot be solved from the equation (12) above. This is linked to the behavior of the scalar multiplication function in (10) (plotted in figure 1 below), that produces two very noticeable effects: a significant contrast increase for very dark gray tones and a significant loss of contrast for the light gray tones (early saturation). Simple corrections are at hand for the mentioned drawbacks.

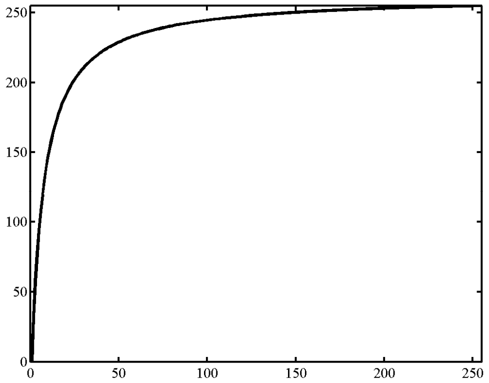

Fig.1.Saturation effect of a gray-level multiplication with a constant scalar (α =36); a significant contrast increase can be noticed for very dark gray tones and a significant loss of contrast can be noticed for the light gray tones (early saturation). Value ranges have been extended to [0,255] for easier comprehension.

To avoid early saturation, we may introduce a restriction on the magnitude of the amplification coefficient α. Denoting by ε a saturation-guard value, the following equation will be used for the computation of the aplification coefficient α :

$$\frac{\alpha\cdot K}{1+(\alpha-1)\cdot K} = 1-\varepsilon \tag{13}$$

Thus, the amplification coefficient α becomes:

$$\alpha = \frac{(1-\varepsilon)\cdot(1-K)}{\varepsilon\cdot K} \tag{14}$$

For a contrast stretching transform, the contrast modification will be given by the derivative of the transform function:

$$C = \frac{\Delta y}{\Delta x} = \frac{T(x_2)-T(x_1)}{x_2-x_1} = \frac{dT(x)}{dx} \tag{15}$$

Thus, deriving equation (11), we obtain that the contrast modification C depends on the parameter ε according to:

$$C(x,\varepsilon) = \frac{\varepsilon\cdot K\cdot(1-2\cdot x)\cdot(1-\varepsilon)\cdot(1-K)}{[(1-\varepsilon)\cdot(1-K)\cdot x+\varepsilon\cdot K\cdot(1-x)]^2} \tag{16}$$

The contrast modification must be upper-limited at the origin (very dark gray tones). If this upper limit is set to some appropriate value T, we obtain the value of the parameter ε as:

$$\varepsilon = \frac{1-K}{T \cdot K - K + 1} \tag{17}$$

Experiments showed that the choice of the contrast modification limit T is not critical and in most cases $T = 4$ yields good-quality, contrast enhanced images.

It is worth to notice that equations (17) and (14), that define the parameters of the contrast stretching transform given by equation (11), are derived under the proposed LLIP framework. The use of any of the Jourlin or Pătraşcu LIP models requires the use of appropriate gray tone multiplication and addition, resulting in different expressions for ε and α .

IV. EXPERIMENTAL RESULTS

The proposed algorithm has been tested on both gray level and color images obtained from various biomedical imaging modalities: X-ray images (mammographies), fluorescent microscopy (neuron images), visible (white) light microscopy (urinary bladder carcinomas).

A. *Gray Level Image Enhancement*

X-ray images are the most typical medical images, mammograms being a particular form. The fundamental enhancement approach in mammography is to obtain an increased contrast of the breast tissue. On the other hand, detecting a subtle mass on a mammography is not a trivial task, as tumors present a large variety of borders and shapes, with edges of low signal to noise ratio [1]. All these presented aspects are even more important when facing dense breast tissue, where the difference between the normal dense tissue and the tumor is below the human perception threshold.

Figures 2 and 3 present the enhancement of medical significant parts of mammograms by the proposed contrast stretching technique under various LIP models. As it can be observed from the experimental results, the proposed algorithm can effectively enhance the overall contrast of the initial image; details that were not initially visible becoming clearly revealed.

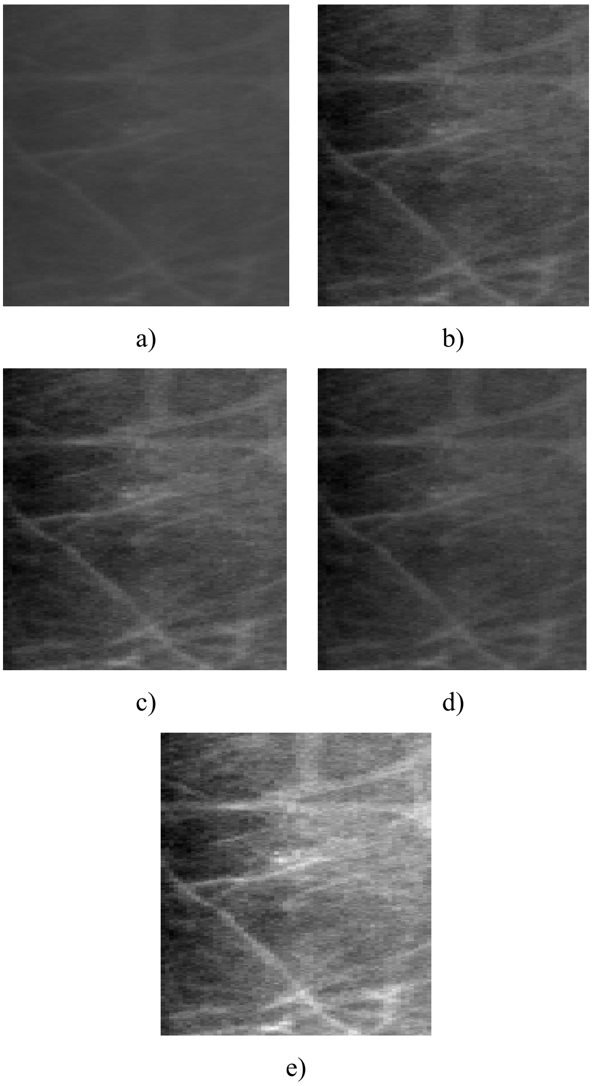

Fig. 2. Contrast stretching of a gray level image (mammogram with fatty-glandular tissue): a) original image; b) enhanced image under the Jourlin LIP model; c) enhanced image under the Pătraşcu LIP model; d) enhanced image under the proposed LIP-like model; e) enhanced image by usual operations.

B. *Color Image Enhancement*

The proposed image enhancement algorithm described in Section II can be extended to color images (such as fluorescent and visible microscopy images) under a simple conditional-type processing. The image is represented in a luminance-chrominance color representation (such as the *YCbCr* color model) and only the luminance component is enhanced according to the presented contrast stretching approach. The color enhancement results are shown in figure 4, for various biomedical images.

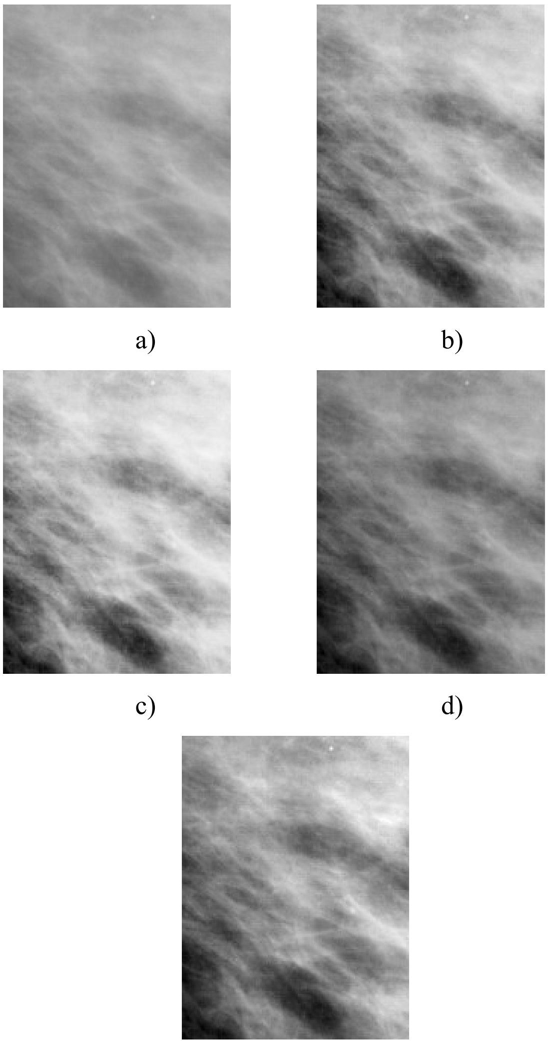
a) b) c) d) e)

Fig. 3. Contrast stretching of a gray level image (mammogram with dense-glandular tissue): a) original image; b) enhanced image under the Jourlin LIP model; c) enhanced image under the Pătraşcu LIP model; d) enhanced image under the proposed LIP-like model; e) enhanced image by usual operations.

V. CONCLUSIONS

This paper presented a new LIP-like model and its application in biomedical image enhancement. The proposed model achieves effective contrast improvements for both gray-level and color images, visually outperforming the implementations based on the existing Jourlin and Pătraşcu LIP models.

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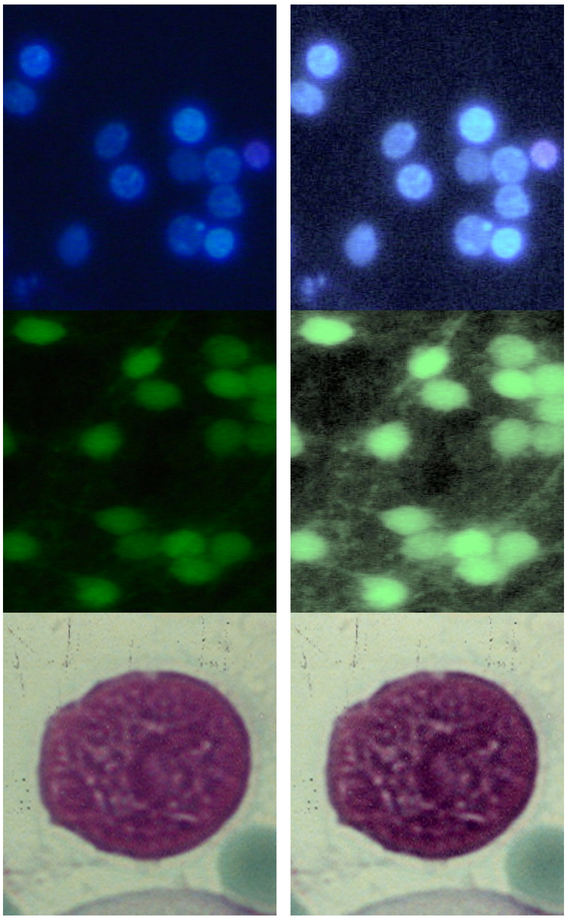

Fig. 4. Color image enhancement examples: original images on the left column, enhanced images by the proposed approach on the right column (first row – neuron kernels in blue fluorescence, second row – neuron cytoplasm in green fluorescence, third row – urinary bladder carcinoma in white light microscopy).

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