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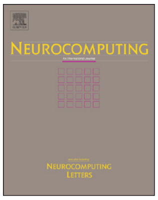

An adaptive approach for texture enhancement based on a fractional differential operator with non-integer step and order

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ABSTRACT

Image texture enhancement is an important topic in computer graphics, computer vision and pattern recognition. By applying the fractional derivative to analyze texture characteristics, a new fractional differential operator mask with adaptive non-integral step and order is proposed in this paper to enhance texture images. A non-regular self-similar support region is constructed based on a local texture similarity measure, which can effectively exclude pixels with low correlation and noise. Then, through applying sub-pixel division and introducing a local linear piecewise model to estimate the gray value in between the pixels, the resulting non-integral steps can improve the characterization of self-similarity that is inherent in many image types. Moreover, with in-depth understanding of the local texture pattern distribution in the support region, adaptive selection of the fractional derivative order is also performed to deal with complex texture details. Finally, the non-regular fractional differential operator mask which incorporates adaptive non-integral step and order is constructed. Experimental results show that, for images with rich texture contents, the effective characterization of the degree of self-similarity in the texture patterns based on our proposed approach leads to improved image enhancement results when compared with conventional approaches.

1. Introduction

Image texture enhancement aims to improve the quality of an image by modifying its attributes. A number of cutting-edge techniques have been proposed which can be divided into two categories: transform-based [1] and spatial domain-based [2]. Transform-based methods regulate coefficients associated with the frequency domain, followed by an inverse transform to obtain the resulting image, based on which image enhancement can be achieved. However, these methods may introduce ringing effect and additional noise. On the other hand, spatial domain-based methods can avoid these problems without the need to perform frequency domain transform, resulting in less computation. Among the different enhancement approaches, the differential mask operator stands out as a particularly important example. Differential operator masks can be further categorized as integral differential and fractional differential operators. As for image improvement, most integral-differential operators (e.g., Sobel, Prewitt, and Laplacian of Gaussian operators) behave well when used for enhancing high-frequency features. Nevertheless, their performance deteriorates significantly when applied to smooth regions.

Pu et al. [3] apply the theory of fractional differential operator to address these problems. Since a fractional differential operator is capable of characterizing fractal-like structures [4] which are often found in the texture regions, this class of operator is considered as an effective tool for texture enhancement in images. Through analyzing the geometric and physical properties of fractional differential operators, Pu et al. [3] have developed an $n \times n$ fractional differential operator mask, and it was noticed that the adoption of the mask results in better enhancement of texture details compared to traditional integral-based differential operators [5]. It was further observed that the fractional differential operator has the capability of not only preserving high-frequency contour features, but enhancing the low-frequency texture details in smooth areas as well. Gao et al. [6] applied the fractional differential operator to quaternions, and designed a set of masks which are referred to as quaternion fractional differential (QFD) operators, which generalize the previous fractional differential operators.

However, for image enhancement, some problems still exist with the fractional differential operator. To begin with, traditional fractional differential operators usually consider fixed-size mask templates, leading to ineffective processing of pixels corrupted by noise and with low correlations. Moreover, the spatial step in the numerical implementation of the fractional differential operator based on the definition of Grümwal–Letnikov usually advances by one. In other words, the default minimum distance is assumed to be one pixel. As a result, the high degree of self-similarity that many images exhibit is not well characterized. In addition, it is not

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convenient to manually search for the optimal fixed fractional derivative order which matches the local texture details. In view of these problems, we propose a novel fractional differential operator mask with adaptive non-integral step and order in this paper for the enhancement of texture details. The main contributions of this paper are as follows:

(1) We identify local non-regular self-similar support regions by analyzing texture features, such that highly correlated pixels can be focused on while noisy pixels are excluded.
(2) We select non-integral steps and fractional orders for the support region in an adaptive way, such that the degree of self-similarity in complex textures can be well characterized.
(3) We design a non-regular fractional differential operator mask with fractional order and adaptive non-integral steps, such that the texture enhancement performance can be optimized regardless of whether the regions consist of high or low frequency patterns.

The paper is organized as follows. The proposed algorithm is introduced in Section 2, followed by the analysis of experimental results in Section 3. Finally, our conclusions are summarized in Section 4.

2. Fractional differential operator mask with adaptive non-integral step and order

As complex textures are characterized by irregular and disorderly patterns, a novel approach based on adaptive fractional differential operator is proposed in this paper to enhance these patterns. Fig. 1 provides an overview of the algorithm. As can be seen, with a suitable texture similarity measure, a local support cross skeleton domain, i.e. $\{h_p^i\}$, where $i \in \{0,1,2,3\}$ denotes the four directions, can be defined. Once such a support skeleton domain, which can be partitioned into two sets $H(p)$ and $V(p)$ corresponding to the horizontal and vertical directions respectively, is determined, a non-regular support region $\Omega_p = \cup_{q \in V(p)} H(q)$ can be constructed. Based on the proposed skeleton domain and its associated support region, the local adaptive fractional order can be dynamically determined, and the result can be computed at a sub-pixel resolution.

2.1. Non-regular support region with self-similarity

Before introducing the non-regular support region, we first define the following notations. As shown in Fig. 2(c), Ω_p is defined as the non-regular neighboring region of an anchor point p. W_p is a square window of radius r which represents the traditional fixed size mask.

Unlike [7] where the pixel value I_p is used as the reference value, we update it dynamically based on a weighted combination of itself and neighboring pixels at a distance h, which makes the skeleton more robust against noise. Considering the right arm h_p^0 of the skeleton for p, the updated reference value is given as

$$\tilde{I}_p^{(h_p^0)} = (1-\alpha)\tilde{I}_p^{(h_p^0-1)} + \alpha I(x+h_p^0, y) \tag{1}$$

where $\tilde{I}_p{}^0 = I_p$, and α is a parameter for controlling the pixel similarity and update rate. Limited by the support radius of W_p, the right span h_p^0 is within the range $[1,r]$. In our case, h_p^0 corresponds to the value of a parameter m ($m \in [1,2,\cdots,r]$), such that the

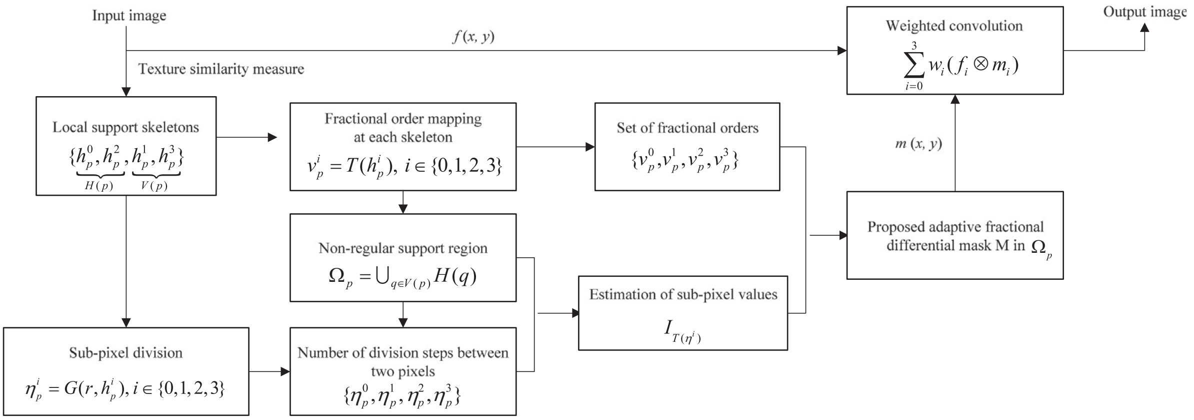

Fig. 1. Block diagram of the proposed method.

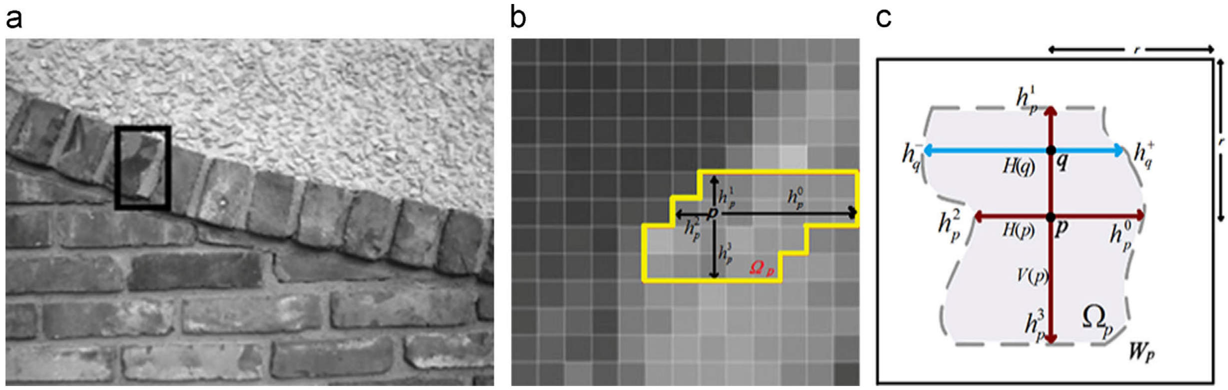

Fig. 2. Local non-regular support region construction: (a) original image, (b) local support region corresponding to the black box in (a), and (c) model of the support region.