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Image denoising via gradient approximation by upwind scheme

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Abstract

A novel hybrid filter based on gradient approximation by upwind scheme is proposed to restore images corrupted by impulsive and Gaussian noises, and simultaneously to preserve the details. In this work, the gradient is approximated by the hybrid upwind scheme, and then the impulses are separated according to the characteristic classification. The remaining pixels are processed by Gaussian filter (GF) with their corresponding weights that are acquired from the hybrid upwind scheme and are distinct in edges and smooth domains. The simulation results demonstrate that the proposed filter achieves better performance in restoring the images corrupted by different noise while the details are preserved.

Keywords: Image denoising; Upwind scheme; Gradient; Hybrid filter

1. Introduction

Images can be corrupted by various noises when they are acquired, transmitted and processed, therefore, image denoising is essential for the subsequent processing stages. Impulsive and Gaussian noise are two kinds of typical noises, up to now, multifarious approaches have been developed to eliminate them. However, two problems still exist. Firstly, a class of filters can only be used to eliminate one kind of the noises significantly, e.g. the median filters have a good performance in reducing the impulsive noise, but they are poor in reducing the Gaussian noise, while the linear filters can reduce the Gaussian noise well but the impulsive noise poorly. Secondly, preservation of image details while eliminating the image noise is usually impossible. They are the irreconcilable conflict during the restoration process. While eliminating the noise, the linear filters blur the image details, and the median filters remove the image features such as long, thin lines and bands. To solve the two problems presented above, the linear and median filters are combined to derive novel filers suitable for the mixed noise environment composed of the Gaussian and impulsive noises in the past two decades. A FIR median hybrid filter [1], which is a cascade of linear phase FIR filters and a median filter, has been developed, and extended to a linear median hybrid filter [2]. The median mean neural hybrid filters has been presented in [3]. And some other hybrid filters are presented in [4–6]. However, the quality of image filtering is still not satisfying, especially when there are many image features.

In this paper, we propose a novel hybrid filter based on gradient approximation by upwind scheme

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(HFGAU). As we know, the gradient values in edges, noise and smooth domain are distinct. The proposed filter approximates the gradient by the hybrid upwind scheme, and then the impulses are separated according to the characteristic classification. The remaining pixels are processed by Gaussian filter (GF) with their corresponding weights that are acquired from the hybrid upwind scheme. The simulation results demonstrate that the proposed filter has a good noise-reducing ability in the mixed noise environment while the details are preserved.

2. Proposed filter

2.1. Introduction of the hybrid upwind scheme

The gradient is an important measure of image features. The gradient value will be small when the domain is smooth and large when the pixel is in edge regions. Upwind scheme is adopted to approximate the gradient in this paper. Assume that X is the noisy image, $X_{i,j}$ is the current pixel to be processed, $D^+X_{i,j}$ and $D^-X_{i,j}$ denote the forward and backward finite difference, respectively. Let

$$D^{+i}X_{i,j} = X_{i+1,j} - X_{i,j}, \tag{1}$$

$$D^{-i}X_{i,j} = X_{i,j} - X_{i-1,j}, \tag{2}$$

$$D^{+j}X_{i,j} = X_{i,j+1} - X_{i,j}, \tag{3}$$

$$D^{-j}X_{i,j} = X_{i,j} - X_{i,j-1}. \tag{4}$$

Then the upwind difference scheme [7] developed by Osher and Sethian [8] is defined as follows:

$$\nabla^+ X_{i,j} = [\max(D^{-i}X_{i,j},0)^2 + \min(D^{+i}X_{i,j},0)^2 + \max(D^{-j}X_{i,j},0)^2 + \min(D^{+j}X_{i,j},0)^2]^{1/2}, \tag{5}$$

$$\nabla^- X_{i,j} = [\min(D^{-i}X_{i,j},0)^2 + \max(D^{+i}X_{i,j},0)^2 + \min(D^{-j}X_{i,j},0)^2 + \max(D^{+j}X_{i,j},0)^2]^{1/2}. \tag{6}$$

According to this scheme, when the impulse is a white pixel or cluster, ∇^+ is positive and ∇^- equals zero, when the impulse is a black pixel or cluster, ∇^- is positive and ∇^+ equals zero. Consequently, it can only distinguish one kind of noise by utilizing one form of the upwind scheme presented above. Then a hybrid diffusive scheme is proposed:

$$\nabla X_{i,j} = \begin{cases} 0 & \nabla^+ X_{i,j} = 0 \\ & \text{or } \nabla^- X_{i,j} = 0 \\ (\nabla^+ X_{i,j} + \nabla^- X_{i,j})/2 & \text{otherwise} \end{cases}. \tag{7}$$

The value will be large in edges, small in smooth domain and zero at the corrupted pixel.

2.2. Impulsive noise separation

There is still one drawback when the hybrid scheme was used to denoise the image. Some details such as bands, roof edges, and lines will be considered as noise too. So we must decide whether it is an edge pixel or a corrupted one when the ∇ value equals zero.

There are three cases when ∇ equals zero:

a. $\nabla^- = 0$ and $\nabla^+ = 0$
The pixel $X_{i,j}$ is in the completely homogeneous domain, it should be left unaltered.

b. $\nabla^- = 0$ and $\nabla^+ > 0$
A four-neighborhood model is introduced. The pixel $X_{i,j}$ with the adjoined pixels like Fig. 1 is considered as an edge pixel and left unaltered, while the pixel in Fig. 2 is considered as noise and processed by median filter.
Then the method for distinguishing the noise is presented as follows:
The four items, $|\max(D^{-i}X_{i,j},0)|$, $|\min(D^{+i}X_{i,j},0)|$, $|\max(D^{-j}X_{i,j},0)|$, $|\min(D^{+j}X_{i,j},0)|$, denote the differences of $X_{i,j}$ in four directions respectively.

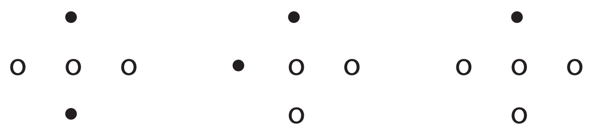

Fig. 1. Three kinds of pixels, which are considered as edge pixels, with their adjoined pixels.

Fig. 2. Two kinds of pixels, which are considered as noise, with their adjoined pixels.