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Rapid and brief communication

The solutions of equation-based noise detector for an adaptive median filter

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Abstract

Techniques of noise detection have been widely applied in impulse noise reduction. However, the phenomenon of pixel misclassification is very obvious in high noise density. In order to improve pixel identification, in this paper, the new noise detector is proposed. Based on solutions of equations, an estimated block of every 8×8 block of a noise image is generated. Then, according to relationships between these noise blocks and their estimated blocks, corrupted and uncorrupted pixels are identified. During image filtering, a noise-detection-based adaptive median algorithm is presented. Experimental results show that the proposed filter can well reduce the impulse noise and preserve more details of original images.

Keywords: Noise detection; Equation; Impulse noise; Median filter

1. Introduction

Median filters have been widely applied in image noise reduction. In order to preserve more details of original images, the topological median filter (TMF) was introduced in Ref. [1]. However, uncorrupted pixels are also processed and the quality of image filtering is degraded. Thus, noise detection is necessary before image filtering. Ref. [2] presented the switching-based median filtering methodology. Since the algorithms made use of a fixed noise-detection threshold, the result of noise detection was not satisfactory. Some remedies of the detector have been proposed, e.g., the neuro-fuzzy impulse noise detector [3]. In order to decrease the number of misclassified pixels, an improved noise detector was presented in Ref. [4]. Although these noise detectors have been improved, results of noise detection and the quality of image filtering are still not satisfactory. Thus, in this paper, the solutions of equation-based noise detector and the noise-detection-based adaptive median filter are proposed.

2. The solutions of equation-based impulse noise detector

In this paper, test images are 512×512 8-bit gray-scale images. The steps of noise detection are described as follows. A noise image is divided into 8×8 blocks, which are neighboring, but do not overlap one another. First, an 8×8 block is taken as an example. Four boundaries of the block are extended outwards by one pixel, i.e., the extension of the block is a 10×10 block. Then, all pixels of four boundaries of the extensive block are processed by standard median filter (SMF), where the size of the filtering window is 11×11. Note that, if the 8×8 block is a boundary block of a noise image, boundaries of its extensive block are generated according to boundary pixels of the noise image. The inner pixels of the extensive block are regarded as unknown variable, and

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Table 1
Effect of different noise densities on noise detection: (a) $\Gamma = \tau_n/\tau_d$; (b) $\Lambda = \tau_n/\tau_a$

	Noise density of images						
	$p = 20\%$	$p = 30\%$	$p = 40\%$	$p = 50\%$	$p = 60\%$	$p = 70\%$	$p = 80\%$
Γ							
peppers	0.97784	0.98901	0.99209	0.99391	0.99456	0.99361	0.98963
*girl*1	0.98898	0.9939	0.99638	0.99584	0.99665	0.99641	0.99147
*girl*2	0.9932	0.99775	0.99839	0.99816	0.99813	0.9976	0.99266
Λ							
peppers	0.99956	0.9999	0.9999	0.99994	0.99985	0.99943	0.99929
*girl*1	0.99962	0.99997	0.99958	0.99963	0.99988	1	0.99905
*girl*2	0.99969	0.99986	0.99987	1	1	0.99991	0.99743

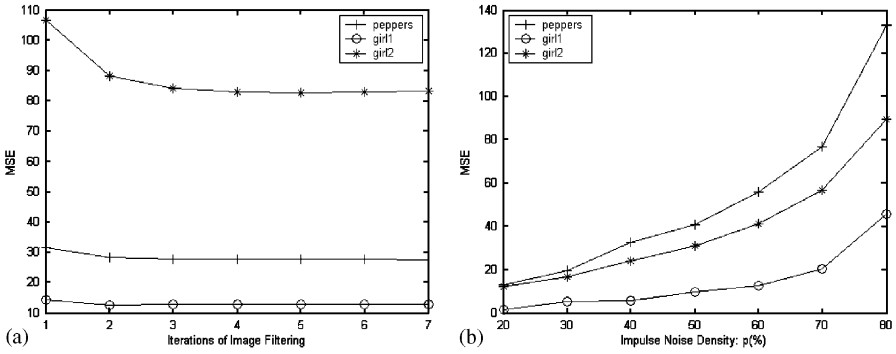

Fig. 1. The performance testing of the proposed filter. (a) Effect of iterations of image filtering on qualities of filtered images; (b) MSE curves of images filtered by the proposed filter in different noise densities.

the pixels of boundaries are transformed into constant terms of the following equations:

$$\begin{cases} FX_1F^{\mathrm{T}} = 0, \\ FX_2F^{\mathrm{T}} = 0, \\ \vdots \\ FX_{64}F^{\mathrm{T}} = 0, \end{cases} \tag{1}$$

where $F = \left[-\frac{1}{2}\ 1\ -\frac{1}{2}\right]$ and X_i is a 3×3 matrix of the extensive block ($i = 1, 2, \ldots, 64$). Note that

$$(2F)^T \bullet (2F) = \begin{bmatrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{bmatrix},$$

where this matrix was presented in Ref. [6].

According to Eq. (1), an estimated block of the original 8×8 block is generated. Let P_{nos} and P_{est} denote two pixel matrices of the original block and its estimated block, respectively. Let $\Delta p(x, y) = p_{nos}(x, y) - p_{est}(x, y)$, where $p_{nos}(x, y)$ and $p_{est}(x, y)$ denote the pixel values of P_{nos} and P_{est} in (x, y), respectively. Let $\Delta p(x_1, y_1), \Delta p(x_2, y_2), \ldots, \Delta p(x_H, y_H)$ be an ascending order of $\Delta p(x_i, y_i) \geqslant 0$, where $1 \leqslant i, j \leqslant 64$. If $\Delta p(x_u, y_u) - \Delta p(x_{u-1}, y_{u-1}) = \max_{1 \leqslant i \leqslant H-1}\{\Delta p(x_{i+1}, y_{i+1}) - \Delta p(x_i, y_i)\}$, the upper bound of pixel identification is $\Delta p(x_u, y_u)$. According to the above-mentioned steps, for $\Delta p(x_j, y_j) \leqslant 0$, the lower bound is also educed. Let the lower bound be $\Delta p(x_l, y_l)$. Thus, rules of noise detection are described by:

(a) If $\Delta p(x, y) \geqslant \Delta p(x_u, y_u)$ or $\Delta p(x, y) \leqslant \Delta p(x_l, y_l)$, $p_{nos}(x, y)$ is regarded as a noise pixel.
(b) Let $p_{nos}(u, v)$ be any pixel of the block. If $p_{nos}(u, v) = p_{nos}(x, y)$ and $p_{nos}(x, y)$ denotes a noise pixel, $p_{nos}(u, v)$ is regarded as a noise pixel in the 8×8 block.

According to the two rules, corrupted pixels of all blocks are identified very well. In a noise image, let Ω_d denote a set of pixels, which are regarded as corrupted pixels by the noise detector. Ω_a denotes a set of all actual corrupted pixels. Test images are shown in Figs. 2(a), 3(a), and 4(a). Test indices include $\Gamma = \tau_n/\tau_d$ and $\Lambda = \tau_n/\tau_a$, where τ_n denotes the number of pixels in $\Omega_a \cap \Omega_d$, τ_d represents that of pixels in Ω_d, and τ_a is that of pixels in Ω_a. Test results are listed in Table 1.

3. The noise-detection-based adaptive median filter

In the section, the noise-detection-based adaptive median filter is presented. Steps of image filtering are presented as follows. In the first iteration of image processing, the size