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Adaptive threshold based fuzzy directional filter design using background information

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ABSTRACT

A novel adaptive fuzzy directional median filter is proposed in this paper which considers the directional pixels (horizontal, vertical and two diagonal directions) for estimation of adaptive threshold and incorporates the remaining background pixels based on directional statistics for efficient noise detection. The proposed filter consists of two phases: adaptive fuzzy noise detection phase followed by fuzzy filtering phase. In fuzzy noise detection phase, intensity differences from the central pixel in a 5×5 sliding window are calculated in four main directions, i.e., horizontal, vertical and two diagonal directions. Average value and central pixel value of 5×5 sliding window of newly constructed intensity differences image are exploited with fuzzy membership function to adaptively estimate threshold parameters. These parameters are then merged with fuzzy rules to detect the noise especially in detailed regions of an image. In filtering phase, simple median filter and directional median filters are smartly used based on edge and background information to restore the noisy pixels detected as noisy in adaptive fuzzy noise detection process. Experimental results based on well known quantitative measures shows the effectiveness of the proposed technique.

1. Introduction

Impulse noise in digital images is frequently introduced during acquisition, storage and transmission due to noisy sensors and communication channels etc. [1]. During this process, some pixel intensities got disturbed while others stay noise free. When impulse noise is added in an image, compatibility of the corrupted pixels becomes compromised with their local neighborhood [2]. Usually, impulse noise is of two types: fixed value and random value. In fixed value impulse noise, pixel value of the corrupted one transforms to 0 (minimum) or 255 (maximum) while in random value impulse noise, pixel value of the corrupted pixel fits into the interval [0,255] for grayscale images [1,2].

A number of linear and non-linear impulse noise removal filters have been proposed. Linear filters are more like average filters and carry out fine filtering but produce blurry effects on restored images because the algorithm considers the noisy and non-noisy pixels equally during the filtering process. Non-linear filters are more robust against the noise because of their computational efficiency and de-noising power [3]. Median (MED) is a well know non-linear filter that restores the corrupted pixel value by taking the median of neighboring pixels around the current pixel. However, median filer might spread the information of edges and lines in detailed region. To handle this issue, a number of median based filters such as center weighted median (CWM) filter [3], switching median (SWM) filter [4], adaptive median (AMED) filter [5], tri-state median filter [6], directional weighted median (DWM) filer [7], multi-stage directional median (MSDM) filer [8], fuzzy reasoning based directional median (FRDMF) filter design [9] and other essential filters have been proposed for impulse noise removal, edge and detail preservation [21–25].

Center weighted median (CWM) filter is a special case of weighted median (WM) filter [4] which restricts the freedom of setting the weights at central location of the window whereas in WM filter, weights can be put at unusual locations of the sliding window. These filters are more robust against additive noise. Switching median (SWM) and adaptive median (AMED) filters perform filtering in two steps – detection step and then filtering step. Noisy pixels are acknowledged in detection phase while pixels detected as noisy are restored with estimated values in filtering phase. AMED preserves low and high noise densities well whereas SWM filter is

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Nomenclature

Abbreviations

CWM	center weighted median filter
SWM	switching median filter
DWM	directional weighted median filter
AMED	adaptive median filter
MSDM	multi-stage directional median filter
FRDMF	fuzzy reasoning based directional median filter design

Symbols

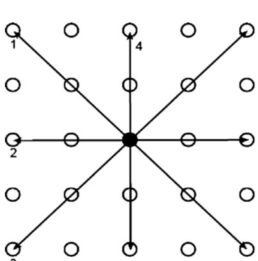
$\eta_{i,j}$	grey level of noisy pixel
p	noise density
Δ_n	intensity differences
δ_d	average directional differences
ν_1	average directional deviation of δ_d
ν_2	central pixel value of average directional deviation of δ_d
μ_{Degree}	membership degree
μ_{LARGE}	membership degree of large
α	first threshold parameter
β	second threshold parameter
MED	median
N	directional index
Ω	5×5 sliding window

heavily dependent on the detection algorithm used in the filtering process.

Directional weighted median (DWM) filter is also a variation of median filter that works excellently in smooth regions of an image. DWM filter first calculates the direction indices for the pixels aligning in horizontal, vertical and diagonal directions and then uses a fixed threshold which works well under some conditions but fails to find correct edge or line directions in detailed regions of an image which ultimately decreases the noise removal capabilities of the DWM filter. Multi-stage median (MSM) filter overcomes the problems of DWM filter by exploiting the background information. MSM filter first calculates the background information by taking the median value of the remaining eight (8) pixels of the convolutionary filter and then finds the standard deviation in four main directions. The smallest standard deviation suggests a possible edge direction. Fuzzy reasoning based directional median filter (FRDMF) design also offers a finer solution by exercising the fuzzy rules and fuzzy membership functions for the problems mentioned in DWM filter.

In this paper we have proposed an adaptive threshold based fuzzy directional filter which considers the directional pixels (horizontal, vertical and two diagonal directions) as well as the remaining background pixels of 5×5 sliding window as shown in Fig. 1(a). For efficient noise detection, the proposed filter works in two phases: adaptive fuzzy noise detection phase and then fuzzy filtering mechanism. In adaptive fuzzy noise detection phase, threshold parameters to filter out the noisy pixels are determined adaptively by exploiting the directional statistics. If the noisy pixel lies in the smooth region then it can be preserved by simple median filter because the median filter preserves the information well in smooth regions. However, if the noisy pixel lies in detailed region then directional median filter is used to restore the noisy pixels. The proposed filter efficiently locates the edge or line and then restores the noisy pixels based on their tight clustering around the mean.

The paper is organized as follows: Section 2 introduces DWM and fuzzy reasoning based directional filter design along with their problems. Noise models are discussed in Section 3, followed by proposed adaptive threshold based fuzzy directional median filer in Section 4. Section 5 presents performance measures. Comparison of results and their discussions are described in Section 6 while conclusions are drawn in Section 7.



(a)

$$\begin{bmatrix} 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & -16 & 1 & 1 \\ 0 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 \end{bmatrix}$$

(b)

Fig. 1. (a) Directions of intensity differences, (b) directional mask.

2. Reviews

Image restoration techniques are developed based on two main assumptions. Firstly, the non-noisy image comprises of smooth regions and these smooth regions are separated by the edges present in the image. Secondly, the intensity of the noisy pixel is quite different from its surrounding pixels. Therefore, in impulsive noise contaminated image, identification of noisy pixel is done by using aforementioned intensity jumps in comparison with its neighboring pixels. Hence, by analyzing the local image statistics within a small window, impulse detection can be performed. Furthermore, classification of pixel which is detected as noisy in smooth region or detailed region, noisy pixel helps in estimation of its intensity value without distorting the detailed/smooth region. Therefore, edge statistics are being used in state-of-the-art filtering techniques for edge preserving noise removal. Fig. 1 shows the edges aligned in four main directions in a local 5×5 window. The sliding window $\Omega_{i,j} = \{f_{i-2,j-2}, f_{i-1,j-1}, \ldots, f_{i+2,j+1}, f_{i+2,j+2}\}$ of size 5×5 centered at location (i,j) consists of 25 intensity values. Let $C_k^{\Omega_{i,j}}$ represent the coordinates of direction k in window $\Omega_{i,j}$ centered at (i,j).

$$C_1^{\Omega_{i,j}} = \{(i-2, j-2), (i-1, j-1), (i+1, j+1), (i+2, j+2)\} \quad (1a)$$

$$C_2^{\Omega_{i,j}} = \{(i, j-2), (i, j-1), (i, j+1), (i, j+2)\} \quad (1b)$$

$$C_3^{\Omega_{i,j}} = \{(i+2, j-2), (i+1, j-1), (i-1, j+1), (i-2, j+2)\} \quad (1c)$$

$$C_4^{\Omega_{i,j}} = \{(i-2, j), (i-1, j), (i+1, j), (i+2, j)\} \quad (1d)$$

In DWM [7], directional indices are computed to find possible edge direction so that the noisy pixels can be distinguished from the edgy pixels. Eq. (2a) is used to compute directional indices for k directions.

$$D_k = \sum\nolimits_{(h,l) \varepsilon C_k^{\Omega_{i,j}}} |\Omega_{i,j}(h,l) - \Omega_{i,j}(i,j)|, \quad \forall\ k = 1, 2, 3, 4. \quad (2a)$$

These direction indices are then used to find the minimum direction index using following equation.

$$D_{min} = Min(D_k), \quad \forall k = 1, 2, 3, 4. \quad (2b)$$

In DWM [7], D_{min} is used to decide whether the current pixel is noisy or not but it cannot correctly classify that whether noise is on the edge or in smooth region. Let us compute the procedure on the sample window shown in Fig. 2.

$$D_{min} = (400, 400, 400, 400) = 400 \quad (2c)$$

For threshold less than 400, pixel will be classified as noisy pixel in smooth region. However it is noisy pixel along the edge.