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Adaptive fuzzy inference system based directional median filter for impulse noise removal

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ABSTRACT

Noise filtering in presence of important image detail information is considered as challenging task in imaging applications. Use of fuzzy logic based techniques is capturing more focus since last decade to deal with these challenges. In order to tackle conflicting issues of noise smoothing and detail preservation, this paper presents a novel approach using adaptive fuzzy inference system for random valued impulse noise detection and removal. The proposed filter uses the intensity based directional statistics to construct adaptive fuzzy membership functions which plays an important role in fuzzy inference system. Fuzzy inference system constructed in this way is used by the noise detector for accurate classification of noisy and noise-free pixels by differentiating them from edges and detailed information present in an image. After classification of pixels, noise adaptive filtering is performed based on median and directional median filter using the information provided by the noise detector. Simulation results based on well known quantitative measure i.e., peak-signal-to-noise ratio (PSNR) show the effectiveness of proposed filter.

1. Introduction

Image restoration is a science that deals with the images degraded with blur, noise or both. Digital images are often corrupted by impulse noise during the acquisition, storage or transmission through communication channels [2]. In this process, some pixel intensities are inevitably distorted while others remain noise-free. The altered pixel intensities do not reveal compatibility with their local neighborhood and if the input image is noisy then subsequent image processes such as segmentation and edge detection as well as object tracking in an image/video may perform poorly [2–5]. Usually, Impulse noise can be classified into two types: *fixed value* and *random value impulse noise*. In *fixed value* impulse noise, a noisy pixel takes either 0 (minimum value) or 255 (maximum value). This type of noise is also called *salt-n-pepper* noise which can be easily detected and removed. On the other hand, random-value impulse noise is quite tricky because the corrupted pixels can take any value from range [0–255] for 8-bit gray scale images [1].

The noise model of random valued impulse noise (RVIN) with noise probability p can be described as follows:

$$I_{i,j} = \begin{cases} O_{i,j'}, & p = 1 - n_p \\ \xi_{i,j'}, & p = n_p \end{cases} \tag{1}$$

where $I_{i,j}$ and $O_{i,j}$ represents pixel values at location (i,j) of the noisy and original image, respectively, and $\xi_{i,j'}$ is a noise rate independent of $O_{i,j}$. To remove the impulse noise, a variety of linear and non-linear filters have been proposed. However, it is observed that non-linear techniques are much better than the linear techniques because of their efficiency in detecting and removing the impulse noise.

Median (MED) filter [2] is a well-known non-linear filter used as backbone in many median based filters because of its computational efficiency and de-noising power for removing impulse noise. MED filter eliminates the noise and carry out filtering process superbly in smooth regions of an image. However, it smears the information of edges and lines in detailed region [6–8]. 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 (TSM) filter [6], selective adaptive weighted median filter (SAWMF) [7], direction based adaptive weighted switching median (DAWSM) filter [8], directional weighted median (DWM) filter [10], fuzzy reasoning-based directional median (FRDM) filter design [11], histogram based fuzzy

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filter [13], random value impulse noise removal based on most similar neighbors (MSN) [29], LULU operators [18] and other median based filters have been proposed for impulse noise removal and detail preservation [20,28].

The weighted median (WM) filter [2] is an extension of median filter which allows the freedom to set the weights at different places in the sliding window. As compared to WM filter, the design and implementation of CWM [3] filter is easier but it restricts the freedom of setting the weight to only central location of the window. In AMED filter [5], filtering is applied to the tainted pixels in the filtering window when corrupted and un-corrupted pixels are discriminated by the AMED filter. The performance of AMED filter is good at low noise densities because a very few corrupted pixels are restored by median values. For better noise removal at higher noise densities, window size is very crucial. It has to be increased which will surely escort to less correlation between the replaced median pixel values and corrupted pixel values. In DAWSM [8] and HEIND [9] filters, algorithms are used for detection of degraded pixels in the image while un-corrupted pixels remain unaffected. DWM filter [10] is another noise removing filter which uses a noise detector based on the differences between the central pixel and the neighboring pixels aligning in horizontal, vertical and two diagonal directions. FRDM filter [11] is also an excellent noise removing filter which offers a better solution for the problem in DWM filter by exploiting the fuzzy reasoning based directional median filter. The noise removal capability goes down when DWM filter fails to find the correct edge or line directions. FRDM filter overcomes the problems of DWM filter by detecting the edge and the line directions correctly by averaging the direction indices of DWM filter. Furthermore, FRDM filter uses a fixed threshold which may alleviate some images or even some regions of an image but will not furnish improved results for whole range of natural images.

In this paper, we have presented an adaptive fuzzy inference system based directional median filter (AFIDM) for the images corrupted with random-valued impulse noise. The proposed AFIDM filter adaptively constructs the fuzzy inference system for each sliding window by inspecting the neighboring directional statistics. Fuzzy inference system constructed in this way deals with the classification problem of noisy and noise-free pixels in smooth as well as detailed regions. Based on accurate classification of pixels, noise adaptive median based filtering technique is applied to the degraded pixels which create balance between noise smoothing and edge preservation in an effective manner. Major contributions of the proposed technique include:

- Proposed technique considers the directional statistics and mean deviations of the pixels in prescribed neighborhood, for the construction of adaptive fuzzy membership functions which serves as one of the major component of the proposed fuzzy inference system based noise detector.
- These membership functions efficiently lead the fuzzy inference system for classification of noise-free, noise in smooth and noise in detailed regions.
- Noise adaptive filtering process uses the median and directional median filter based on noisy pixel's category determined by the fuzzy inference system. Filter, besides making tradeoff between noise smoothing and edge preservation, restores the noisy pixel accurately.

Rest of the paper is organized as follows: Section 2 describes the proposed AFIDM filter. Quantitative and qualitative metrics are described in Section 3. Section 4 presents the simulations results along with their analysis and finally conclusions are drawn in Section 5.

2. Adaptive fuzzy inference system based filter

Proposed technique consists of two major processes namely fuzzy inference system based noise detector and noise filtering as shown in Fig. 1. Fuzzy inference system is developed by using the directional indices and their mean deviations adaptively for each considered window and then detailed as well as smooth region pixels are classified into noisy and non-noisy categories. The inference system developed in this way handles uncertainty effectively by distinguishing details from the noisy components. Fuzzy inference system gives noise map as output which is being used by the noise filtering module. Noise map labels the corresponding pixel in degraded image into three classes: 0, 1 or 2 based on the classification achieved through fuzzy inference system. Pixels labeled as 1 or 2 are classified as noisy pixels in smooth region, or detailed region pixels in the degraded image respectively, however label 0 indicates noise free pixel. Noisy pixels are considered as candidate for noise filtering. Based on classification, noise filtering module uses the edge or smooth region preserving filter adaptively. Complete details of these modules are given in the following subsections.

2.1. Adaptive fuzzy inference system based noise detector

The proposed impulse noise detector is based on adaptive fuzzy membership functions which are constructed using the concept of directional statistics and their mean deviations. These membership functions serve as the key component of the fuzzy inference system which is ultimately used in the detection process. Impulse detector constructs noise map, where corresponding pixels in the degraded

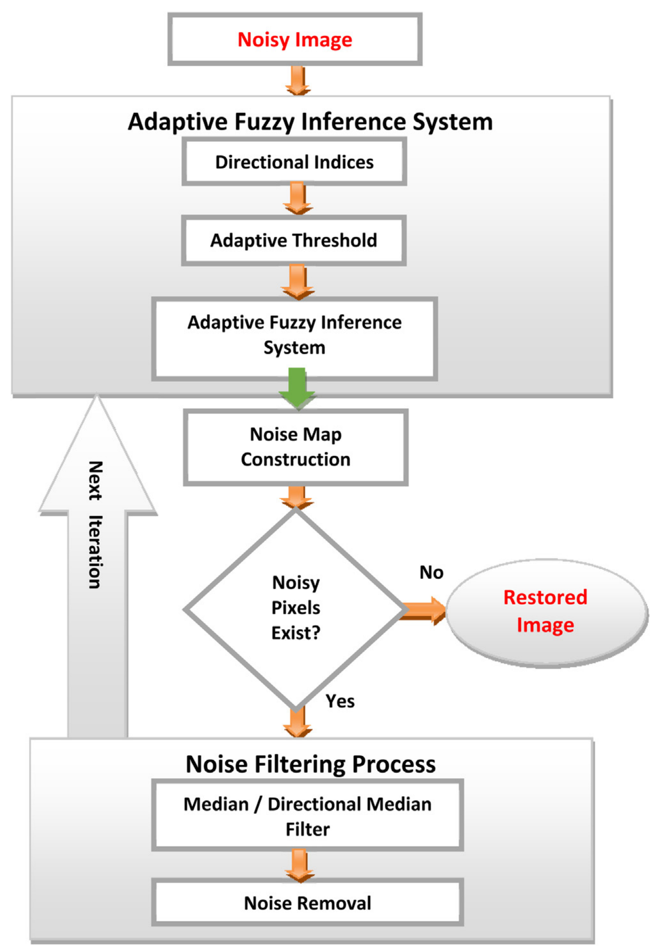

Fig. 1. Proposed system architecture of AFIDM filter.