Signal Processing 121 (2016) 81–93

Contents lists available at ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

A new image denoising method using interval-valued intuitionistic fuzzy sets for the removal of impulse noise

V.P. Ananthi [a,b], P. Balasubramaniam [a,*]

[a] Department of Mathematics, Gandhigram Rural Institute – Deemed University, Gandhigram 624302, Tamil Nadu, India

[b] Visiting Research Fellow, Center for Image and Signal Processing, Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 11 June 2015
Received in revised form
14 September 2015
Accepted 25 October 2015
Available online 10 November 2015

Keywords:
Membership function
Impulse noise
Entropy
Fuzzy set
Hesitation degree

ABSTRACT

Suppressing noise in digital images is more significant in the field of image processing. In this paper, a novel impulse noise detection method is introduced based on fuzzy sets. Generally fuzzy sets are associated with type-1 vagueness, but interval-valued intuitionistic fuzzy sets (IVIFSs) are tied up with type-2 linguistic uncertainty in which the width of the interval represents vagueness. The proposed method investigates image denoising by modeling this vagueness as entropy. An IVIFS for an image is generated by minimizing entropy. Then type-reduced IVIFS is obtained by taking probabilistic sum of the membership interval. Finally, noisy pixels are detected using directional kernels and are filtered using fuzzy filter. Performances are evaluated using mean square error (MSE), peak signal-to-noise ratio (PSNR), mean absolute error (MAE) and structural similarity (SSIM) index. A comparative analysis on the quality of denoised images shows that the proposed technique performs better than several existing median filters.

1. Introduction

One of the fundamental problems in image processing and computer vision is the elimination of noise. An image can be degraded due to several factors during acquisition and transmission, which leads to a significant reduction in its quality [1]. Noise in images may exist in three different forms namely impulsive, additive and multiplicative noise. This degradation causes negative effects in other image processing tasks such as image segmentation, compression, edge detection and so on. Therefore it is necessary to reduce noise in images before commencing other image processing tasks. Typically, impulse noise has a main characteristic that some portion of image pixels will be affected and some pixels remain unaffected. Two main types of impulse noise are random valued noise and salt & pepper noise [2].

One of the preliminary goals of image denoising is to reduce noise in images by retaining image features. This can be solved by non-linear filters more effectively than linear filters. Median filter outperforms linear filters, but image features are smoothened by median filters [3]. In order to overcome this issue, several state-of-the-art filtering techniques have been emerged such as optimal weighted median filter (OWMF) [4], adaptive median filter (AMF) [5], tristate median filter (TSMF) [6], switched median filter (SMF) [7], triangular fuzzy filter with median center and with average center, asymmetrical triangular fuzzy filter with median center (ATMED) and with average center (ATAVG), adaptive center weighted median filter (ACWMF) [8], adaptive fuzzy switching weighted average filter (AFSWAF) [9] and progressive switching median filter (PSMF) [10]. Recently numerous techniques have been developed for image denoising such as local adaptive filter

* Corresponding author.
E-mail address: balugru@gmail.com (P. Balasubramaniam).

http://dx.doi.org/10.1016/j.sigpro.2015.10.030
0165-1684/

[11], principal component analysis [12], content-based adaptive filter [13], non-local means [14], fractional order differentiation [15], local adaptive patch filtering in wavelet domain [16], progressive image denoising [17], adaptive guided filter [18] and rough set based filtering [19]. Another emerging machine learning technique namely sparse representations has become a trend and is used for restoration problems. An iterative nonlocal multi-scale dictionary learning scheme in the wavelet domain has been recently investigated for image denoising in [20]. The general idea of dictionary learning based methods is that they perform denoising by learning a large group of patches from an image dataset such that each patch in the estimated image can be expressed as a linear combination of only few patches from this redundant dictionary [21,22].

After the introduction of fuzzy sets (FSs) by Zadeh [23] in 1965, it has been utilized in various domain especially in the field of image processing. It deals with the data that contains vagueness. For example, in noisy images uncertainty emerges in opting affected pixels out of the unaffected one using their intensity levels. To remove the above problem of uncertainty, intuitionistic fuzzy set (IFS) [24] is employed. One cannot assure the assignment of intensity value (generated by reducing redundancy) to the image pixels as an exact number which perfectly portray that image. Assigning a fixed membership value to a pixel is restrictive, so allotting an interval of value instead of fixed value is more realistic. IVIFS [25] is more suitable for this issue and such problem has not yet taken into account during noise removal in the existing literature.

The proposed scheme of noise reduction initially transfers the vague noisy image into IVIFS domain for eliminating the above redundancy. In IVIFS domain, L-IVIFSs are produced for each single noisy image and among these L-IVIFSs, one IVIFS is selected which has minimum entropy. A new type-reduced membership degree is generated from the membership interval of the chosen IVIFS by employing probabilistic sum. The values of type-reduced membership are convolved with four 5×5 convolution kernels, which are sensitive to all possible directions to detect noisy pixels. Then fuzzy filtering method is applied to the set of detected noisy pixels. Finally filtered image is defuzzified to get a denoised image without impulsive noise. Quantitative measures such as mean square error (MSE), peak-signal to noise ratio (PSNR), mean absolute error (MAE) and structural similarity (SSIM) index are computed for the filtered images to show the performance of the proposed filter over other existing methods.

This paper is framed as follows. Few recent median based filtering techniques that are related to the present study are discussed in Section 2. Section 3 describes some preliminary ideas on fuzzy sets (FSs) and its extended sets such as intuitionistic fuzzy sets (IFS) and interval-valued intuitionistic fuzzy sets (IVIFS). Section 4 describes about the construction of IVIFSs for digital images. Algorithm of the proposed denoising technique is explained in Section 5. Section 6 provides experimental and comparison results. Finally, conclusion is drawn in Section 7.

2. Related works

The most well known nonlinear filter for noise reduction is the median filter [3]. Many techniques to remove high level of noise have been developed based on median filter. Among them, this paper focuses on the filters described in references [2,4–10,26,27]. Recent methods (in references [2,9,26,27]) for the removal of noise in images are briefly explained below.

In AWMF [2], the noisy pixels are chosen by checking its intensity value equals to either 0 or 255. The adaptive window for applying a filter to those selected noisy pixels is chosen in such a way that the maximum and minimum values in two consecutive windows are equal. For example, consider a 5×5 window centered around a noisy pixel, whose maximum and minimum intensity values are determined respectively as 0 and 255, then search for the maximum and minimum intensity values using the next window size 7×7 is assured to be similar. If these values are the same in both the windows, then the adaptive window size is chosen as 5×5. Otherwise, the search of the window is continued till a stopping criterion is reached. After such detection, the set of noisy pixels are replaced by the weighted median value of the appropriate window. Finally, median filter is again applied to image generated by a fuzzy membership function defined using local information extracted by maximum absolute difference.

AFSWAF [9] method uses the similar technique for detection of noisy candidate by using fuzzy similarity measure and Gaussian membership function by fixing a threshold and size of the window as 3×3 instead of α-trimmed mean function and iterative increasing of threshold and window size. This method also uses weighted mean filtering scheme for denoising the selected noisy candidate. One can clearly see that the noisy pixels in the above detection methods are detected by searching the pixel's intensity value is either 0 or 255.

NAFSMF [26] filtering technique incorporates the behaviors of adaptive and fuzzy switched median filters into a single filter. This filter detects the location of the noise impaired pixels by searching the lower intensity level (0) and the higher intensity level (255) in the image using both the extremities of the histogram. The selection of the window size for filtering is done by searching the neighbors of the noise impaired pixel with at least one of the neighbors belongs to noise free pixels set. Then the new value of the noise impaired pixel is the median value of its neighbors. Otherwise, the size of the window is increased by 1 and then median value of neighbors in the new window is employed in place of the noise impaired pixel.

The difficulty faced by switching based method is in deciding a pre-defined threshold. To overcome the difficulty in defining threshold, MDBUTMF is introduced in [27]. Since it is introduced for SPN, the pixels with extreme values are alone processed and the remaining pixels are left unaltered. Noisy pixels are processed according to the values in its 3×3 neighbor. If the 3×3 neighbor contains only the intensity values 0 and 255, then their mean value is replaced in the place of noisy candidate; otherwise