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A Review & Analysis of Image Filters for Impulse Noise

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***Abstract*—** Filtering is an essential part of any signal processing system. This involves estimation of a signal degraded, in most cases, by additive random noise. Several filtering techniques have been proposed where linear processing techniques have been the method of choice for many years because of their simplicity. Most of these techniques, however, assume a Gaussian model for the statistical characteristics of the underlying process and try to optimize the parameters of a system for this model. Nonlinear techniques have recently assumed significance as they are able to suppress noise to preserve important signal elements such as edges and fine details and eliminate degradations occurring during signal formation or transmission through nonlinear channels. A detailed literature survey has been done here to compare these conventional image filters with a iterative approach. This paper includes an analysis about the significance of iteration based approach for image filtering.

***Keywords*—** Image Processing, Filters, Denoising

I. INTRODUCTION

Image noise is random variation of brightness or color information in images, and is usually an aspect of electronic noise. It can be produced by the image sensor and circuitry of a scanner or digital camera. Image noise can also originate in film grain and in the unavoidable shot noise of an ideal photon detector. Image noise is an undesirable by-product of image capture that obscures the desired information.

The original meaning of "noise" was "unwanted signal"; unwanted electrical fluctuations in signals received by AM radios caused audible acoustic noise ("static"). By analogy, unwanted electrical fluctuations are also called "noise"[4][2].

Image noise can range from almost imperceptible specks on a digital photograph taken in good light, to optical and radio astronomical images that are almost entirely noise, from which a small amount of information can be derived by sophisticated processing. Such a noise level would be unacceptable in a photograph since it would be impossible even to determine the subject. An introduction to various types of noise and filters is given in the background Section II. The work related to conventional image filters and fuzzy filters is presented in Section III followed by the analysis of the same in section IV.

II. BACKGROUND

This section aim to present a study related to various types of noise and filters. The types of noise are:

Gaussian noise: Principal sources of Gaussian noise in digital images arise during acquisition. The sensor has inherent noise due to the level of illumination and its own temperature, and the electronic circuits connected to the sensor inject their own share of electronic circuit noise [3].
Salt-and-pepper noise: Fat-tail distributed or "impulsive" noise is sometimes called salt-and-pepper noise or spike noise. An image containing salt-and-pepper noise will have dark pixels in bright regions and bright pixels in dark regions. This type of noise can be caused by analog-to-digital converter errors, bit errors in transmission, etc [3].

Shot noise: The dominant noise in the brighter parts of an image from an image sensor is typically that caused by statistical quantum fluctuations, that is, variation in the number of photons sensed at a given exposure level. This noise is known as photon shot noise [3].

Quantization noise: The noise caused by quantizing the pixels of a sensed image to a number of discrete levels is known as quantization noise. It has an approximately uniform distribution. Though it can be signal dependent, it will be signal independent if other noise sources are big enough to cause dithering, or if dithering is explicitly applied [19].

Film grain: The grain of photographic film is a signal-dependent noise, with similar statistical distribution to shot noise. If film grains are uniformly distributed (equal number per area) and each grain has an equal and independent probability of developing to a dark silver grain after absorbing photons, then the number of such dark grains in an area will be random with a binomial distribution. In areas where the probability is low, this distribution will be close to the classic Poisson distribution of shot noise [19].

Anisotropic noise: Some noise sources show up with a significant orientation in images. For example, image sensors are sometimes subject to row noise or column noise [19].

Periodic noise: A common source of periodic noise in an image is from electrical or electromechanical interference during the image capturing process [15]. An image affected by periodic noise will look like a repeating pattern has been added on top of the original image. In the frequency domain this type of noise can be seen as discrete spikes. Significant reduction of this noise can be achieved by applying notch filters in the frequency domain.
There are various filters that help to denoise the image as discussed as under:

Median Filter: Median filter is a nonlinear kind of image filtering which is effectively used in reducing the image noise while maintaining the edges of the image. One advantage of median filtering is eliminating the effect of input noise values with very large magnitudes.

Linear Filter: Linear filtering [15] can be used to remove certain types of noise. Certain filters, such as averaging or Gaussian filters, are appropriate for this purpose. For example, an averaging filter is useful for removing grain noise from a photograph. Since each pixel gets set to the average of the pixels in its neighbourhood, local variations caused by grain are reduced. Linear filtering is filtering in which the value of an output pixel is a linear combination of the values of the pixels in the input pixel's neighbourhood. Linear filtering of an image is accomplished through an operation called convolution. Convolution is a neighbourhood operation in which each output pixel is the weighted sum of neighbouring input pixels. The matrix of weights is called the convolution kernel, also known as the filter. The main disadvantage of convolution filter is, it is not good for all type of noise. It is sensitive to variations in orientation and scale. It is also sensitive to non-uniform illumination.

Adaptive Filter: The wiener function applies a Wiener filter [15] (a type of linear filter) to an image adaptively, tailoring itself to the local image variance. If the variance is large, wiener performs little smoothing. If it is small, wiener performs more smoothing. This approach often produces better results than linear filtering. The adaptive filter is more selective than a comparable linear filter, preserving edges and other high-frequency parts of an image. In addition, there are no design tasks; the wiener2 function handles all preliminary computations and implements the filter for an input image. It require more computation time than linear filtering. Wiener works best when the noise is constant power ("white") additive noise, such as Gaussian noise. Another method for removing noise is to evolve the image under a smoothing partial differential equation similar to the heat equation which is called anisotropic diffusion.

Nonlinear filter: In recent years, a variety of nonlinear median type filters [22] such as weighted median, rank conditioned rank selection, and relaxed median have been developed. Two important nonlinear filters include median filter and fuzzy filter.

A median filter is an example of a non-linear filter and, if properly designed, is very good at preserving image detail. To run a median filter: 1. Consider each pixel in the image 2. Sort the neighbouring pixels into order based upon their intensities 3. Replace the original value of the pixel with the median value from the list A median filter is a rank-selection (RS) filter, a particularly harsh member of the family of rank conditioned rank-selection (RCRS) filters; a much milder member of that family, for example one that selects the closest of the neighbouring values when a pixel's value is external in its neighbourhood, and leaves it unchanged otherwise, is sometimes preferred, especially in photographic applications. Median and other RCRS filters are good at removing salt and pepper noise from an image, and also cause relatively little blurring of edges, and hence are often used in computer vision applications.

Fuzzy Filter: Fuzzy filters provide promising result in image processing tasks that cope with some drawbacks of classical filters. Fuzzy filter is capable of dealing with vague and uncertain information. Sometimes, it is required to recover a heavily noise corrupted image where a lot of uncertainties are present and in this case fuzzy set theory is very useful. Each pixel in the image is represented by a membership function and different types of fuzzy rules that considers the neighbourhood information or other information to eliminate filter removes the noise with blurry edges but fuzzy filters perform both the edge preservation and smoothing. Image and fuzzy set can be modeled in a similar way. A fuzzy set is a class of points possessing a continuum of membership grades, where there is no sharp boundary among elements that belong to this class and those that do not. This membership grade is expressed by a mathematical function called membership function or characteristic function. This function assigns to each element in the set. The membership maps each element to a membership grade between 0 and 1.

Iterative Mean Filter: Iterative Mean Filter (IMF) is used to eliminate the salt-and-pepper noise. IMF uses the mean of gray values of noise-free pixels in a fixed-size window. Unlike other nonlinear filters, IMF does not enlarge the window size. A large size reduces the accuracy of noise removal. Therefore, IMF only uses a window with a size of 3×3. This feature is helpful for IMF to be able to more precisely evaluate a new gray value for the center pixel.

Conservative Smoothing : Conservative smoothing [7] is a noise reduction technique which employs a simple, fast filtering algorithm that sacrifices noise suppression power in order to preserve the high spatial frequency detail (e.g. sharp edges) in an image. It is explicitly designed to remove noise spikes, i.e. isolated pixels of exceptionally low or high pixel intensity (e.g. salt and pepper noise) and is, therefore, less effective at removing additive noise (e.g. Gaussian noise) from an image. Like most noise filters, conservative smoothing operates on the assumption that noise has a high spatial frequency and, therefore, can be attenuated by a local operation which makes each pixel's intensity roughly consistent with those of its nearest neighbours. However, whereas mean filtering accomplishes this by averaging local intensities and median filtering by a non-linear rank selection technique, conservative smoothing simply ensures that each pixel's intensity is bounded within the range of intensities defined by its neighbours. Conservative smoothing is less corrupting at image edges than either of these noise suppression filters. Conservative smoothing works well for low levels of salt and pepper noise. But it is unable to reduce much Gaussian noise as individual noisy pixel values do not vary much from their neighbours. Conservative smoothing works well for low levels of salt and pepper noise. However, when the image has been corrupted such that more than one pixel in the local neighbourhood has been effected, conservative smoothing is less successful

III. RELATED WORK

The study related to various filters employed to remove different types of noise is given in this section.
The iterative mean filter (IMF) has been proposed **[5]** to eliminate the salt-and-pepper noise. The work in **[6]** present an improved median filtering algorithm. The process was modified by identifying the noise density of the image and the window size of the image will be the basis to be used in sorting the pixel. Furthermore, the median value replaces the pixel value in the entire window. The result shows that the modified median filtering has a detailed and clearer output.

[17] used different methods to separate noisy and noiseless pixels, such as any machine learning or deep learning method (ANN, CNN, SVM), thereby maintain the textural information. Last stage uses spatial domain filter to remove any residual noise present. Thus obtained image resembles more with the original image. This constitutes for presence of white and black spots on the image. So it is necessary to remove this noise, and to obtain a much clearer image. By taking the advantage of both spatial domain and frequency domain filter, a more effective method of de-noising is proposed. The image is denoised in three folds. First step includes preprocessing by using spatial domain filters, second stage uses frequency domain filter to avoid blurring and smoothing effect on the image. [1] evaluated the performance of different edge detection algorithms; Canny, Prewitt, LOG, and Laplacian with and without adding filer such as wiener and median. The statement of effectiveness in removing noise and preserving important information in medical image is identified by using quality measurements like PSNR and MSE. Edge detection is a common process in the treatment of medical images and it is a very useful task for object recognition of human organs. Edge detection also show where shadows fall in an image or any other distinct change in the intensity of an image due to noise effects.

[21] proposed a novel iterative two-stage method to suppress salt and pepper noise. In the first phase, a multilevel weighted graphs model for image representation is built to characterize the gray or color difference between the pixels and their neighbouring pixels at different scales. Ten the noise detection is cast into finding the node with minimum node strength in the graphs. In the second phase, we develop a method to determine the order-inducing variables and weighted vectors of the induced generalized order weighted average (IGOWA) operator to restore the detected noise candidate. In the proposed method, the two stages are not separate, but rather alternate [20] included numerous underwater image enhancement techniques developed in the recent years along with the limitations and challenges in it. These techniques are helpful to detect the edges or patterns present in the input images, used in different applications such as computer vision, medical imaging, underwater imaging and other multimedia applications to detect the objects or patterns in a given input image. Due to the degradation of color, light absorption and scattering, artificial light, suspended particles in underwater, the acquired images are having low contrast or very dim in color and causes only one color to dominate the entire image. Hence, the identification of the objects in the underwater image becomes tricky. After the image acquisition, preprocessing step is must to increase the quality of the degraded images for image processing and underwater or marine applications.

A number of digital filters such as mean filter, median filter, wiener filter, and adaptive filter are applied**[3]** for the removal of different level of Gaussian noise, salt and pepper noise and speckle noise separately in MR images. The performance of all the filtering techniques is compared on the basis of the statistical parameters such as Peak Signal to Noise Ratio (PSNR) and Root Mean Square Error (RMSE). Therefore, acquisition of images without noise is nearly impossible task. Various filtering techniques are used to reduce the noise for further analysis of medical images. [14] proposed an improved algorithm that incorporates the function of bilateral filter model and wavelet thresholding using Neighshrink SURE method. The results show significant improvement in both PSNR and IQI values with respect to the four standard test images under various noise conditions**.** Since noise cannot be reduced to zero practically, the need for faithful and efficient denoising techniques to produce almost noiseless images demands a systematic research work in the field of denoising methods. The denoising process using a bilateral filter even though produces improvement in the image quality, it does not show consistency when the noise level

is high and also the peak signal to noise ratio (PSNR) and Image quality Index (IQI) do not show any improvement.
In**[8],** an interactive hybrid Gaussian image denoising technique based on trilateral filtering and Gaussian condition random field approach is proposed. The trilateral filter is edge preserving Gaussian filter and Gaussian condition random field use deep neural network to deal with different noise levels. [11] proposed interval type-2 fuzzy filter (IT2FF) based color image filtering algorithm for reducing additive noise that consists of two sub filters. The first sub filter computes the distance between the color components of the central pixel and its neighbourhood, which determines the degree by which each component should be corrected. The second sub filter computes the local difference with in the color component.

In NR-IQA technique [9], the distributions of local gradient orientations in image regions of different sizes are used to characterize an image. To evaluate the objective quality of an image, its luminance and chrominance channels are processed, as well as their high-order derivatives. Finally, statistics of used perceptual features are mapped to subjective scores by the support vector regression (SVR) technique. [13] presented a new extension of Gaussian mixture models (GMMs) based on type-2 fuzzy sets (T2 FSs) referred to as T2 FGMMs. The estimated parameters of the GMM may not accurately reflect the underlying distributions of the observations because of insufficient and noisy data in real-world problems. By three-dimensional membership functions of T2 FSs, T2 FGMMs use footprint of uncertainty (FOU) as well as interval secondary membership functions to handle GMMs uncertain mean vector or uncertain covariance matrix, and thus GMMs parameters vary anywhere in an interval with uniform possibilities. [3] proposed an algorithm for designing linear equalizers that maximize the structural similarity (SSIM) index between the reference and restored signals. The SSIM index has enjoyed considerable application in the evaluation of image processing algorithms. Algorithms, however, have not been designed yet to explicitly optimize for this measure. The design of such an algorithm is nontrivial due to the non convex nature of the distortion measure. In this paper, we reformulate the non convex problem as a quasi-convex optimization problem, which admits a tractable solution. We compute the optimal solution in near closed form, with complexity of the resulting algorithm comparable to complexity of the linear minimum mean squared error (MMSE) solution, independent of the number of filter taps. The summary related to different contributions is presented in TABLE 1 for the filters, type of noise, evaluation parameters, dataset used along with the results as improvements.

Srinivasan[9]. In this algorithm, pixels having minimum (0) and maximum values (255) are deemed as corrupted. Such pixels are replaced by median of 3 * 3 neighbourhood window provided that median itself is not noise (0 or 255) otherwise pixels are replaced by last processed neighbourhood value. This filter performs well at low noise densities. At high noise density streaking occurs due to replacement with neighbourhood pixel value [21]. Removal of Salt-and Pepper Noise in Images: A New Decision Based Algorithm proposed by Madhu S. Nair et al.[10], utilizes impulse noise detection scheme of AMF and processes corrupted pixels by median of neighbourhood window of 3 * 3 size or by mean of previously processed neighbourhood pixels if median happens to be noisy pixels. This algorithm is faster and efficient at low noise density. At high noise density, it happens that median value is coming from a noisy pixel which leads to streaking effect.

Removal of High Density Salt and Pepper Noise through Modified Decision Based Unsymmetric Trimmed Median Filter (MDBUTMF) is proposed by S. Esakkirajan[20]. In this filter, every corrupted pixel is processed by 3 * 3 neighbourhood window. If all neighbouring pixels are 0's and 255's then current pixel is replaced by mean of neighbourhood window else if not all neighbouring pixels are 0's and 255's then current pixel is replaced by median of neighbouring uncorrupted pixels. At high noise density, this algorithm fails if all the elements within the window are '0' or '255' then the mean value will be '0'or '255' hence noisy pixel will not be efficiently processed [18]. A Decision-based Filter for Removing Salt-and-Pepper Noise is proposed by Muhammad Mizanur Rahman[12]. This Non Linear Decision Based Filter (NDBF) also filters only corrupted pixels (pixels having values 0 or 255). It replaces corrupted pixel by median of 3*3 neighborhood window only if median value is not one of the extreme gray levels. If median value is 0 or 255, it checks value of Last Processed Pixel (LPP). If LPP is noise free then it takes neighborhood window of 10*10 size and calculates median and mode this window. If this median is noise free then current pixel is replaced by LPP else current pixel is replaced by mode. If LPP is noisy pixel, then eight 3*3 sized adjacent windows of current window are considered. Modes of these 9 windows are calculated and then current pixel is replaced by mode of these 9 mode values. In this way all corrupted pixels are filtered and finally robust estimator is applied on filtered image for enhancement.[11] have proposed High Density Salt and Pepper Noise Removal through Decision Based Partial Trimmed Global Mean Filter (DBPTGMF) in [18]. It overcomes drawback of MDBUTMF. It also uses 3 * 3 neighborhood window to filter each noisy pixel having value 0 or 255. If neighborhood window contains all elements as 0 then current pixel is replaced by salt noise (255) trimmed global mean value of image else if neighborhood window contains all elements as 255 then current pixel is replaced by pepper noise (0) trimmed global mean value of image else if neighborhood window contains all elements as 0 and 255 both then current pixel is replaced by salt and pepper noise (both 0 and 255) trimmed global mean value of image else current pixel is replaced by median of uncorrupted neighboring pixels. This methods give excellent result at low and medium noise densities. But at high noise density i.e. above 60% noise it has a poor IEF value and lead to blurring the image [21].

Satyabrata Biswall have proposed decision based algorithm in [18]. In this algorithm, noisy pixel is replaced by mean of neighboring pixels if all neighbors are corrupted. If some neighboring pixels are 0 or 255 or both then these corrupted neighboring pixels are trimmed and current pixel is replaced by mean of remaining noise free pixels.

TABLE 1: Summary of Image Filters

Ref	Filter Used	Noise	Parameter	DataSet	Improvement
[1]	median, wiener	Salt &pepper, Gaussian	PSNR, MSE	X-Ray	Canny improved edge detection
[3]	Modified Median Filtering	impulse noise	Noise Density	traffic images	detailed and clearer output compared to median filtering
[4]	MSE-optimal filter	Additive white gaussian noise	SSIM, MMSE	blurred and corrupted	denoising and restoration
[5]	Iterative Mean Filter	salt-and-pepper noise	PSNR, SSIM	IMAGESTEST BPDF (25.36 /0.756)	precisely evaluate a new gray value for the center pixel
[7]	adaptive filter	Gaussian noise	RSNR, RMSE	MRI Images	Supress Noise
[8]	trilateral filter	Gaussian noise	RMSE, PSNR	Distorted Image	refined edges and not remove any detail present in the image
[13]	Type-2 Fuzzy Filter	additive noise	PSNR, MSE	Color image	efficient and produces better restoration
[15]	Fuzzy Filter	Additive	MSE	Color Images	performs better for all noise levels and for all window sizes

IV. CONCLUSION AND FUTURE SCOPE

During image acquisition and transmission, noise is seen in images. This is characterised by noise model. So study of noise model is very important part in image processing. On the other hand, Image denoising is necessary action in image processing operation. Without the prior knowledge of noise model we cannot elaborate and perform denoising actions. Hence, here we have reviewed and presented various noise models available in digital images. On the basis of various noise models some image filters are also reviewed in this paper like fuzzy filter, median filter, linear filter, non linear filter, adaptive filter and Iterative Mean Filter. Among all these filters Iterative Mean Filter is suitable for particularly Salt and Pepper noise.

REFERENCES

[1]. Anas, R.; Elhadi, H.A.; Ali, E.S.; “Impact of Edge Detection Algorithms in Medical Image Processing”, World Scientific News, vol: 118, 2019, pp: 129-143

[2]. Arabinda Dash and Sujaya Kumar Sathua, “High Density Noise Removal By Using Cascading Algorithms”, Fifth International Conference on Advanced Computing & Communication Technologies 2015, doi: 10.1109/ACCT.2015.100

[3]. Bangug, C.M.; Fajardo, A.C.; Medina, R.P.; “A Modified Median Filtering Algorithm (MMFA)”, International MultiConference of Engineers and Computer Scientists, 2019, pp: 377-380

[4]. Channappayya, S.S.; Bovik, A.C.; Caramanis, C.; Heath, R.W. “Design of linear equalizers optimized for the structural similarity index”, IEEE Trans Image Process, vol: 17, No: 6, 2008

[5]. Erkan, U.; Thanh, D.N.H.; Hieu, L.M.; Enginoglu, S.; “An Iterative Mean Filter for Image Denoising”, IEEE, vol: 7, 2019, pp: 167847-167849

[6]. G. Balasubramanian, A. Chilambuchelvan, S. Vijayan and G. Gowrison, “An extremely fast adaptive highperformance filter to remove salt and pepper noise using overlapping medians in images”, The Imaging Science Journal, 64:5, pp. 241-252, doi: 10.1080/13682199.2016.1168144

[7]. Garg, S.; Vijay, R.; Urooj, S.; “Statistical Approach to Compare Image Denoising Techniques in Medical MR Images”, Procedia Computer Science, vol: 152, 2019, pp: 367-374

[8]. Kaur, N.; Verma, P.; Verma, G.N. “A Novel Hybrid Image Denoising Technique based on Trilateral Filtering and Gaussian Condition Random Field Model”, International Research Journal of Engineering and Technology, vol: 6, 2019, pp: 2124-2129

[9]. K. S. Srinivasan and D. Ebenezer, “A New Fast and Efficient Decision-Based Algorithm for Removal of High Density Impulse Noises,” IEEE Signal Processing Letters, Vol. 14, NO. 3, March 2007, doi: 10.1109/LSP.2006.884018.

[10]. Madhu S. Nair, K. Revathy, and Rao Tatavarti, “Removal of Salt-and Pepper Noise in Images: A New DecisionBased Algorithm”, Proceedings of the International MultiConference of Engineers and Computer Scientists 2008 Vol I, IMECS 2008, 19-21 March, 2008, Hong Kong, doi:

[11]. Md Tabish Raza and Suraj Sawant , “High Density Salt and Pepper Noise Removal Through Decision Based Partial Trimmed Global Mean Filter”, 2012 Nirma University International Conference on Engineering (NUiCONE), doi: 10.1109/NUICONE.2012.6493236
[12]. Muhammad Mizanur Rahmani, M. Abdullah-AI-Wadud and Chrysanthe Prezal, “A Decision-based Filter for Removing Salt-and-Pepper Noise”, IEEE/OSA/IAPR International Conference on Infonnatics, Electronics & Vision 2012, doi: 10.1109/ICIEV.2012.6317513
[13]. Murugeswari, P.; Manimegalai, D.; “Noise Reduction in Color image using Interval Type-2 Fuzzy Filter (IT2FF)”, International Journal of Engineering Science and Technology, Vol. 3 No. 2, 2011, pp: 1334-1338
[14]. Mu-Hsien Hsieh , Fan-Chieh Cheng, Mon-Chau Shie, Shanq-Jang Ruan, “Fast and efficient median filter for removing 1–99% levels of salt-and-pepper noise in images”, Engineering Applications of Artificial Intelligence 26(2013), pp. 1333-1338, doi: 10.1016/j.engappai.2012.10.012
[15]. Naragund, M.N.; Jagadale, B.N.; Priya, B.S.; Hegde, V.; “An Efficient Image Denoising Method based on Bilateral filter Model and Neighshrink SURE”, International Journal of Recent Technology and Engineering, vol: 8, 2019, pp: 8470-8475
[16]. Oszust, M.; “No-Reference Image Quality Assessment with Local Gradient Orientations”, Symmetry, vol:11, No: 1, 2019
[17]. Ranjitha, S.; Hiremath S. G.; “High Density Impulse Noise Removal and Edge Detection in SAR Images based on Frequency and Spatial Domain Filtering”, International Journal of Engineering and Advanced Technology, vol: 8, 2019, pp: 643-648
[18]. Satyabrata Biswall and Nilamani Bhoi, “A new filter for removal of salt and pepper noise”, 2013 International Conference on Signal Processing, Image Processing and Pattern Recognition [ICSIPR], doi: 10.1109/ICSIPR.2013.6497990
[19]. Sudhakar, M.; Meena, M.J.; “Underwater Image Enhancement using Conventional Techniques with Quality Metrics”, International Journal of Innovative Technology and Exploring Engineering, vol: 8, 2019, pp: 241-249
[20]. S. Esakkirajan, T. Veerakumar, Adabala N. Subramanyam, and C. H. PremChand, “Removal of High Density Salt and Pepper Noise Through Modified Decision Based Unsymmetric Trimmed Median Filter”, IEEE Signal Processing Letters, Vol. 18, No. 5, May 2011, doi: 10.1109/LSP.2011.2122333
[21]. Xu, Q.; Zhang, Q.; Hu, D.; Liu, J.; “Removal of Salt and Pepper Noise in Corrupted Image Based on Multilevel Weighted Graphs and IGOWA Operator”, Mathematical Problems in Engineering, vol: 2018, 2018, pp: 1-12
[22]. Zeng, J.; Liu, Z.; “Type-2 fuzzy Gaussian mixture models”, Pattern Recognit, 2008.