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Modified Wiener Filter for Restoring Landsat Images in Remote Sensing Applications

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ABSTRACT

Images are inherently affected by different noises such as, speckle, salt and pepper, Gaussian, poisson, and white noise during its acquisition or transmission, hence, their true intensities cannot be reflected from the pixel values of an image. The main focus of this work is on designing a filtering method that preserves the edges of an image while removing the noise. The modified wiener filter is proposed to denoise satellite images. A detailed study on different noises and the filtering techniques, such as mean, median, wiener, Gaussian filter and the proposed modified wiener filter is done. The performance of these filtering methods is assessed by the image quality metrics, such as mean squared error, peak signal to noise ratio, and correlation coefficient. The results show the choice of a filter for denoising depends on the type of noise present in the image. The proposed modified wiener filter performs relatively well for most of the noise models compared with the existing linear and non-linear filtering methods. This technique can be widely used during the pre-processing of satellite images in remote sensing applications.

Keywords: Image denoising, filtering, remote sensing applications, peak signal to noise ratio, satellite images, Modified wiener filter

INTRODUCTION

Images are prone to degradation by noise, distortion and artefacts from various sources either at the time of image acquisition or transmission which are mainly due to improper imaging system, inappropriate focusing, movement etc (Jain & Tyagi, 2014). Employing feature extraction and classification algorithms on noisy images paves way for inaccurate conclusion. Hence, these noises in images must be removed in the pre-processing phase. The ratio of the

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corrupted pixels in the image decides the quantification of the noise. Image denoising is an essential task in many applications where the image is restored by retaining as much as possible information with the use of filtering techniques (Ansari & Budhhiraju, 2016; Wang, Ziou, Armenakis, Li, & Li, 2005). Hence, reliable filtering techniques are required to restore the image with the essential information for accurate image analysis.

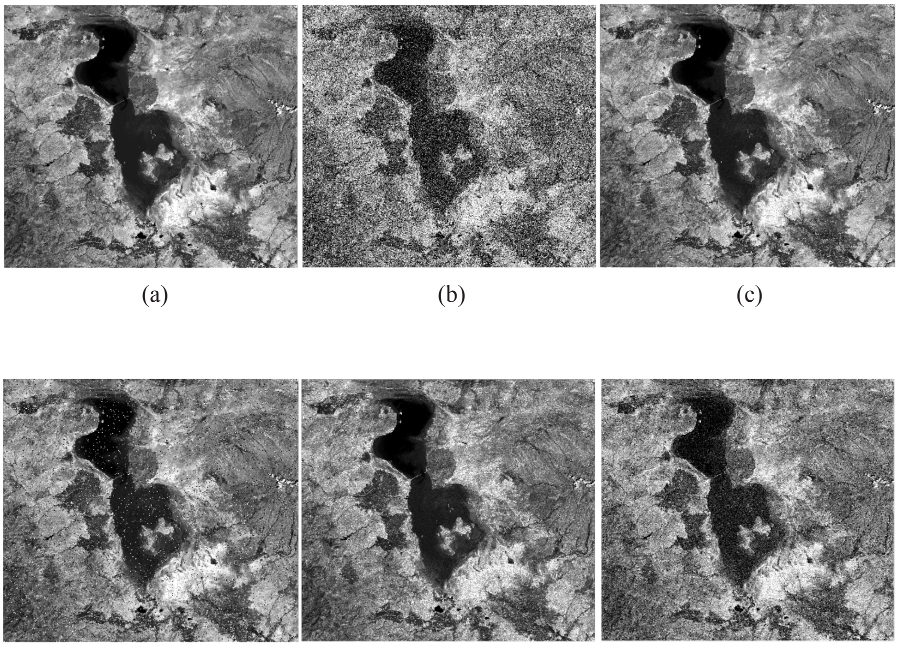
A number of noise removal algorithms is available and a detailed study on different noises and the filters are required to choose a suitable technique for any particular application. Different noises that may present in images include impulse noise, Gaussian noise, Poisson noise, Speckle noise and so on (Bovik, 2010). The impulse noise occurs mainly due to the sudden and severe disturbances in an image signal. This noise is also referred as salt and pepper noise because the majority of the pixels are in black and white. For an 8-bit image, the pixel intensity value 0 and 255 refers to the pepper and salt noise respectively.

The Gaussian noise model is additive in nature and follows Gaussian distribution. In other words, it is referred to as a statistical noise having the probability density function close to normal distribution. The intensity of each pixel in the noisy image is the sum of the Gaussian distributed noise value and the true pixel value. The communication channels suffer from Gaussian noise because of the thermal vibrations, particularly in telecommunication and networking.

Poisson or Photon noise refers to the uncertainty in the measurement of light during the image acquisition. In digital and film-based sensors, the photoelectric effect on image scene brightness leads to photon noise. Speckle noise is a multiplicative noise triggered by consistent processing of backscattered signals from several objects of focus. It is a signal dependent form of noise whose magnitude is associated with the value of the original pixel. This noise follows a gamma distribution. Images captured or acquired through laser, acoustics, Thematic Mapper (TM) and Synthetic Aperture Radar (SAR) results in multiplicative noise. A generic radiometric calibration cannot be used optimally for detecting targets in various applications; hence, a specific filtration based on the requirement is essential.

Surface water is one of the invaluable assets for human survival and social development. True data about the spatial distribution of surface water is essential for various applications, such as water resource assessment, environment monitoring, climate modelling, water survey and management among others. Water features can be extracted from different bands of Landsat imagery. Hence, the images must be free from noises to further detect and map the spatiotemporal changes using various surface water extraction techniques. Lake Urmia has a total area of approximately 51,876 km^2 in the north west of Iran (Eimanifar & Mohebbi, 2007). The lake has been in a catastrophe for recent years because of decreasing surface water and increasing salinity.

This study aims to enhance and restore the Landsat TM images of Lake Urmia. The images are taken from USGS (US Geological Survey) Global Visualisation Viewer. The noise is added to the test image in a controlled manner to obtain a corrupted image. The original and noisy images of Lake Urmia are shown in Figures 1(a-f).



(a) (b) (c)

(d) (e) (f)

Figure 1. (a) Lake Urmia, Landsat 5 Original image, (b) Image with Gaussian Noise, (c) Image with Poisson Noise, (d) Image with Salt and Pepper Noise, (e) Image with Speckle Noise, (f) Image with White Noise

FILTERING TECHNIQUES

Image filtration is also known as image denoising, an operation to clean the image from a degraded noise affected image. Filtering is the process of altering pixel intensity values to know certain image characteristics. Filtering is done on images for various purposes such as:i) to enhance by improving the contrast; ii) to smoothen by removing the noises; and iii) to do template matching by detecting the known patterns.

Filtering is a neighbourhood process, in which the value of every pixel in the output image is found by applying an algorithm to all the neighbourhood pixel intensities of the corresponding input pixel. Hence, the boundary pixels require additional rows and columns to be padded before applying the filter. The amount of padding depends upon the kernel size and generally it can be done in four different ways known as zero padding, reflection, replication and extrapolation. Zero padding is done by placing zeros in the outer padded region. Pixel replication is easily done by copying the border pixel intensities and placing the same in the outer padded region. In reflection padding, the outer padded region is filled with mirror reflection of boundary to inner pixels based on the kernel size. Extrapolation can be done by padding with a linear extension of the outmost two border values.

The filtering techniques are broadly classified as linear and non-linear (Plataniotis & Venetsanopoulos, 2013). Linear filtering is a process in which the value of an output pixel is a linear combination of the pixel intensities of the input pixel's neighbourhood. Linear filtering techniques removes noise within a short span of time but it does not preserve edges. Non-linear filters are the vice versa of linear filters, wherein their output is not a linear function of their input and these techniques are good at preserving the edges of an original image.

The corrupted image is denoised using various existing filters, such as mean, median, Gaussian, wiener and the proposed modified wiener filter. The performance of the denoised image is measured based on the quality assessment metrics such as Peak Signal to Noise Ratio (PSNR) and Correlation Coefficient (CORR) (Kalaivani & Phamila, 2016). The filters achieving the highest PSNR, CORR and less computational complexity can be assumed as the best filter for a particular noise model. Peak Signal to Noise Ratio measures the quality of the filtered image and the value will be high when the resultant image is identical to the original image. The PSNR is calculated using the formula:

$$PSNR = 10\log_{10}\frac{r^2}{MSE}$$

where MSE is the Mean Squared Error and r is the peak value of the original / reference image. Higher value of PSNR indicates better filtration. The correlation coefficient (Roche, Malandain, Pennec, & Ayache, 1998) represents the similarity between the corrupted image and original image with respect to the pixel intensity. It can be computed using the formula:

$$CORR(A,B) = \frac{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\ (A(m,n)-\mu_A)\ (B\ (m,n)-\mu_B)}{\sqrt{(\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}(A(m,n)-\mu_A))^2)(\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\ (B(m,n)-\mu_B)^2\ )}}$$

where μ_A and μ_B are the mean values of filtered and original images respectively. The value of correlation coefficient lies between 0 and 1, if the value is 0, then it indicates the complete loss of information and 1 indicates maximum similarity.

Mean Filter

Mean filter is an averaging linear filter, which uses a spatial mask over each pixel in an image. Usually the size of the mask will be odd so that the central pixel can be found easily. The value of the pixels which are grouped under the mask is averaged and this is known as the centre pixel intensity (Verma & Jahid, 2013). This averaging eliminates pixel values which are unrepresentative of their surroundings. Mean filter is a convolution filter as they are represented using a matrix multiplication. It works as follows:

i. Pad the outer region of boundary pixels.

ii. Apply a mask over a pixel of a noisy image.

iii. Find an average: add the pixel intensities of all the pixels which fall under the mask and divide by the total number of elements in the mask.

iv. Assign the average value to the centre pixel of the kernel.

v. Repeat the steps ii, iii and iv for all the pixels of an image.

It reduces the amount of intensity variation between adjacent pixels thereby restoring the affected image. An averaging filter of size 3 × 3 is employed to filter the multidimensional array of the input noisy images of Lake Urmia (Figure 1 b-f). The PSNR and Correlation coefficients are computed for all the filtered images of different noises and their performance are shown in Figure 2.

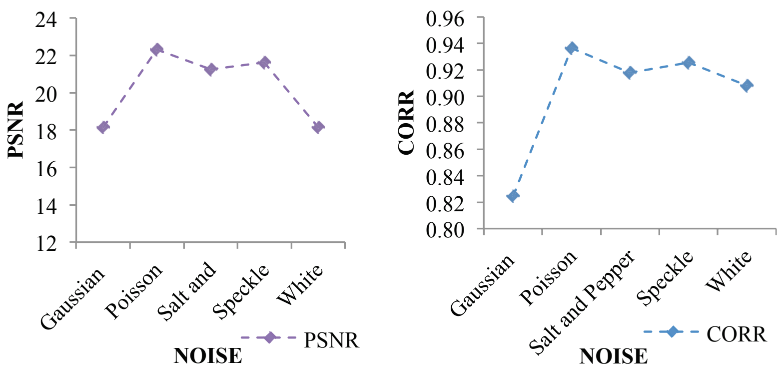


Figure 2. PSNR and CORR results of Mean filter

Median Filter

Median filter is a non-linear robust filter, which preserves the edge details than the mean filter. This filtering technique also uses a mask over each pixel and replaces the centre value with the median of its local neighbourhood pixel intensities. The pixel intensities, which fall under the mask, are sorted and the middle pixel value is considered as the median. Instead of replacing the centre pixel value with the average of neighbouring pixel values, it replaces with the median (Chen, Church, & Rice, 2008). The working principles are as follows:

i. Pad the outer region of boundary pixels.
ii. Apply a mask over a pixel of a noisy image.
iii. Sort the pixel intensities of all the pixels which fall under the mask.
iv. Find the median and assign it to the centre pixel of the kernel.
v. Repeat the steps ii, iii and iv for all the pixels of an image.

Salt and pepper noise is highly reduced by median filters without any loss of fine edge details (Chan, Ho, & Nikolova, 2005). The input matrix of all noisy images is median filtered in two dimensions using the default filter size 3 × 3. This is done for all the considered noisy images (Figure 1b-f) and their performance based on PSNR values and correlation coefficient is shown in Figure 3.

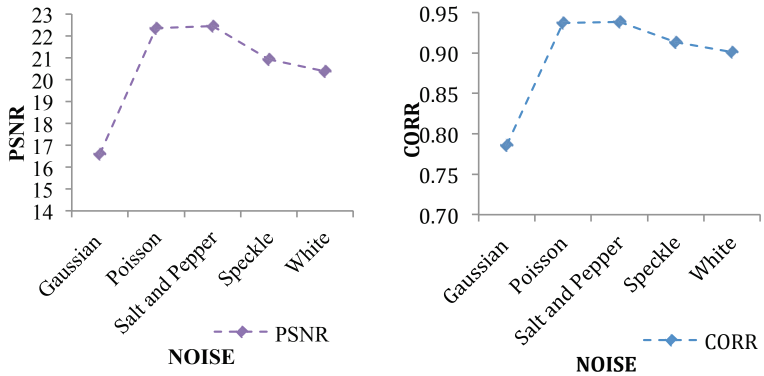


Figure 3. PSNR and CORR results of Median filter

Gaussian Filter

It is a linear smoothing filter with the weight chosen according to the form of a Gaussian function (Kumar, Murugan, & Rajalakshmi, 2015). A Gaussian filter can be generated from PASCAL's triangle, and these filters can be applied recursively to create a Gaussian pyramid. The 3 × 3 kernel / mask is created from third row of the Pascal's triangle. It is a particular class of averaging filter. The filter works as follows:

i. Pad the outer region of boundary pixels.

ii. Generate and apply a Gaussian mask over a pixel of a noisy image.

iii. Perform an element-by-element multiplication with this pixel neighbourhood and sum up all the elements.

iv. Assign the resultant sum to the centre pixel of the kernel.

v. Repeat the steps ii, iii and iv for all the pixels of an image.

The test images are filtered with a 2-D Gaussian smoothing kernel with 0.5 as standard deviation. The noisy images (Figure 1 b-f) are filtered using the Gaussian kernel and their performance based on PSNR and correlation coefficient is shown in Figure 4.

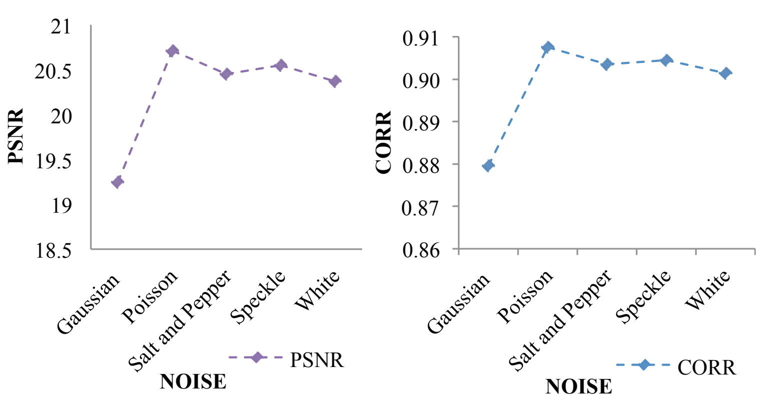


Figure 4. PSNR and CORR results of Gaussian filter

Wiener Filter

It is an additive noise removal filtering process. The low pass wiener filters use the pixel wise adaptive method based on facts assessed from a local neighbourhood of each pixel. It computes the local mean and variance in its process of filtering. It performs deconvolution by inverse filtering and removes the noise by a compression operation (Jiang, Yang, Wang, & Hou, 2014; Yoo & Ahn, 2014). The wiener filter works as follows:

i. Estimate the power spectra (Fourier transform of the auto correlation function) of the original and noisy image.

ii. Apply a mask over a pixel of a noisy image.

iii. Calculate the local mean (μ) and variance (σ^2).

iv. Compute the new pixel value using the mean, variance and noise power.

v. Repeat the steps ii to iv for all pixels of a noisy image.

Wiener filtering acts as the optimal trade-off between noise smoothing and inverse filtering. The wiener filter is applied to all noisy images (Figure 1(b-f)) and the performance is evaluated based on the PSNR values and correlation coefficient obtained. The results are shown in Figure 5.

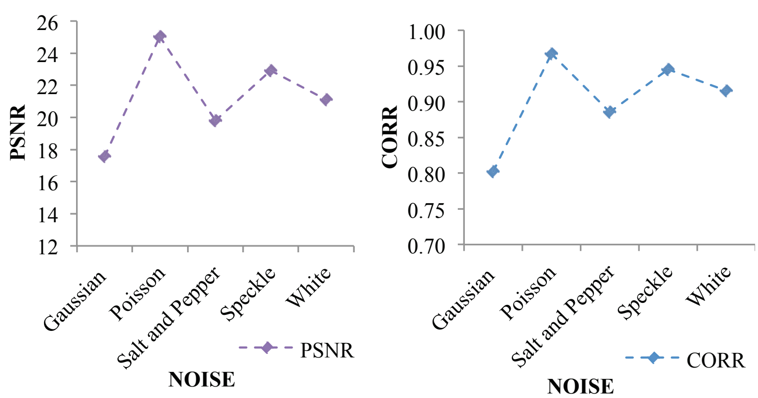


Figure 5. PSNR and CORR results of Wiener filter

Modified Wiener Filter

The proposed modified wiener filter is an additive noise removal technique where median is computed for all the pixels using a 3 × 3 filter. The resultant matrix is further processed similar to the wiener filter. This non-linear adaptive spatial filter is proposed with the aim to combine the features of median filter and wiener filter reciprocally nullifying their defects. The working of the proposed filter is shown as flow diagram in Figure 6. The modification of the wiener filter is very significant due to the non-linear behaviour of the median operator in adaptive contest. The main objective is to preserve the edges without modifying the shape and structure while reducing the noise in an image.

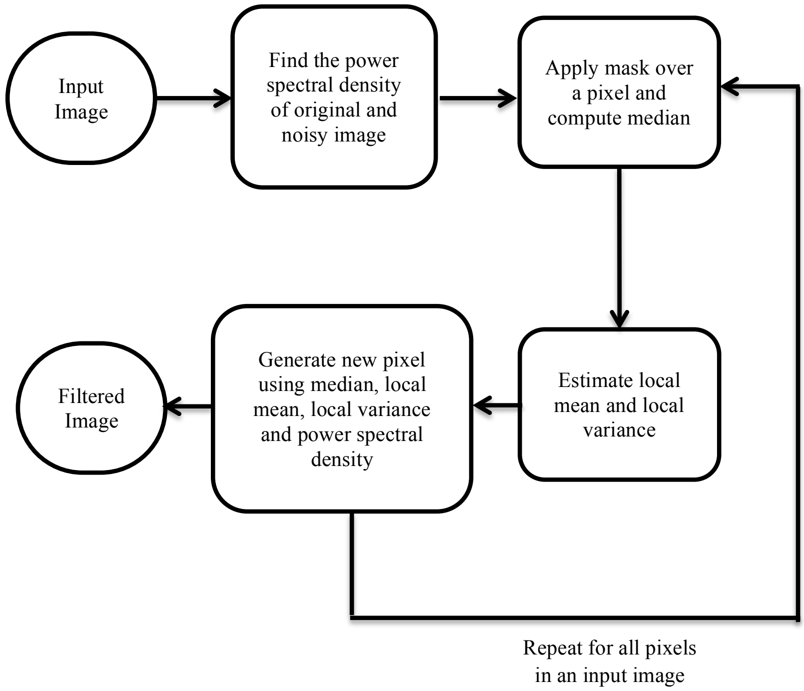


Figure 6. Flow diagram of Modified Wiener filter

Calculating median instead of mean reduces noise without blurring the edges and therefore, this edge preserving nature makes the proposed filter useful in applications where edge blurring is undesirable. The algorithm of modified wiener filter is as follows:

i. Estimate the power spectral density (Fourier transform of the auto correlation function) of the original and noisy image.

ii. Apply mask over a pixel of the noisy image.

iii. Sort the pixel intensities of all the pixels which fall under the mask.

iv. Find the median (med) and assign it to the centre pixel of the mask.

v. Estimate the local mean (μ) and variance (σ^2)

   a. $Mean\ (\mu) = \frac{1}{mn}\sum_{mn} A(m,n)$, where m and n represent the row and column of an image A.

   b. $Variance\ (\sigma^2) = \frac{1}{mn}(A(m,n) - \mu)^2$, where m and n represent the row and column of an image A.

vi. Compute the new pixel value *B (m, n)*

   $B\ (m,n) = med + \frac{\sigma^2 - V^2}{\sigma^2}\ (A(m,n) - med)$, where v^2, med represents the noise variance and median value of the local window respectively.

vii. Repeat the steps ii to vi for all pixels of a noisy image.

The proposed filter is applied on different types of noisy images and the resultant filtered images are shown in Figure 7(a-j).

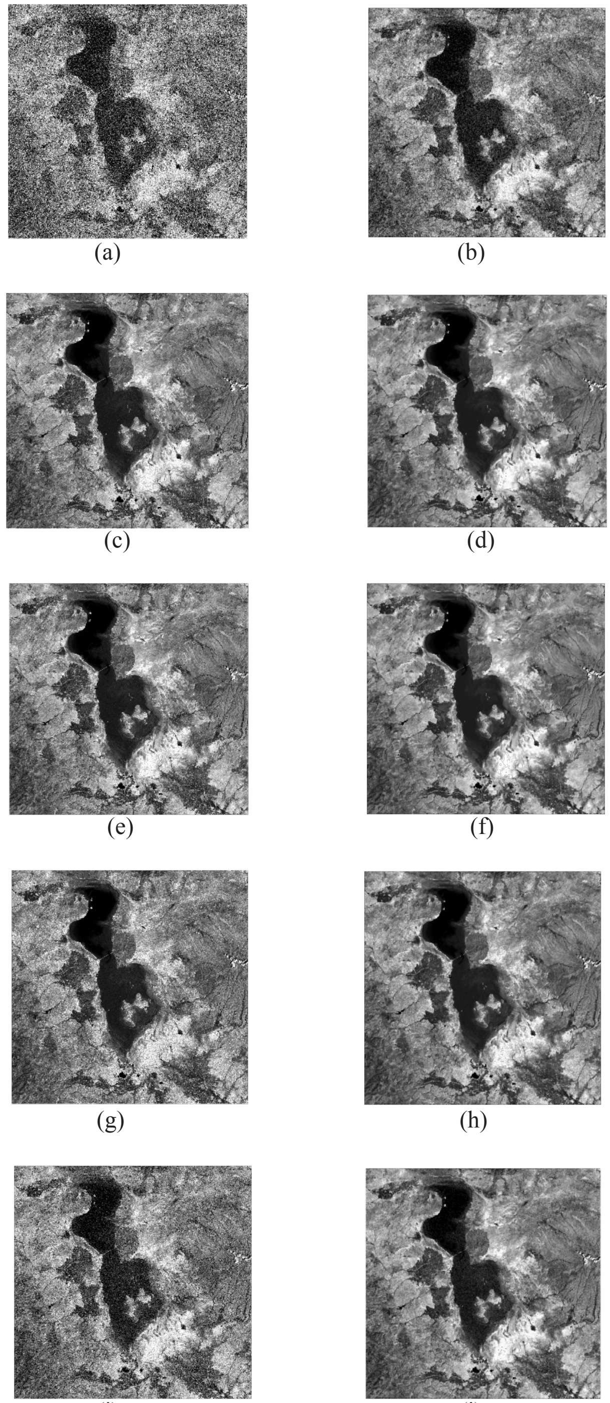

(a) (b)
(c) (d)
(e) (f)
(g) (h)
(i) (j)

Figure 7. (a) Image with Gaussian noise, (b) Modified wiener filter on Gaussian noise affected image, (c) Image with Poisson noise, (d) Modified wiener filter on Poisson Noise affected image, (e) Image with Salt and Pepper noise (f) Modified wiener filter on Salt and Pepper noise affected image, (g) Image with Speckle noise, (h) Modified wiener filter on Speckle noise affected image, (i) Image with White noise, (j) Modified wiener filter on White noise affected image

The performance of modified wiener filter is evaluated based on PSNR values and correlation coefficient of the processed image in the presence of various noises (Figure 1(b-f)) and the results are represented in Figure 8.

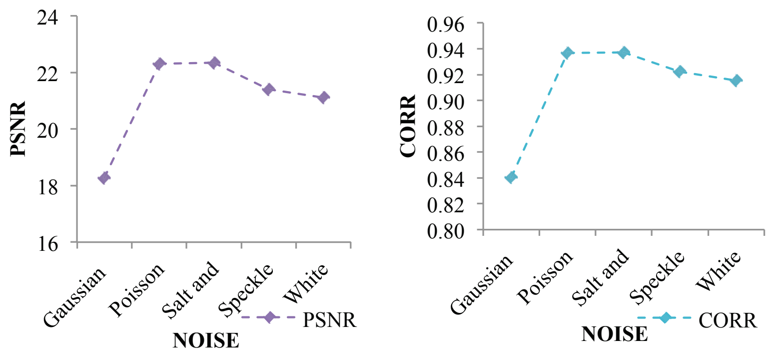


Figure 8. PSNR and CORR results of Modified Wiener filter

RESULTS AND DISCUSSION

The performance and appropriate use of a particular filter for any application is still an ongoing research (Darus et al., 2017; Verma & Jahid, 2013). The mean filter is the simplest linear spatial filter, which assigns the average value of the pixels in the window (mask) as the centre value. A new denoised value is computed for each pixel by moving the window across the pixels of an image, hence, this filter is called as moving average filter. This averaging filter is good at removing the grain noise in an image. Because of the averaging of neighbouring pixels, local variations caused by grain noise are greatly reduced.

Median filter is the non-linear spatial filter, which can be widely used to remove impulsive noises like salt and pepper noise effectively. It can be employed in applications where there is a necessity to preserve edges while removing noise (Ismail, Adnan, Malek, & Bebakar, 2008). Median filter is more effective in preserving edges, the reason is that it is less sensitive to extreme values called outliers (Chen et al., 2008) when compared with mean. The median filter erodes the edges of isolated spots when the window size is large while the Gaussian filter blurs the image and remove noises and some essential information.

Images from US Geological survey, such as Lake Turkana, Huang he Delta (Yellow River), Lake Urmia, Capecod USA and the images from Remote Pixel Earth Observation Dataset are considered for evaluating the performance of existing and modified wiener filters in the presence of various noises. The PSNR values of different filtration techniques on various noises of study image Lake Urmia are shown in Table 1 and Figure 9.

Table 1
PSNR values of different filtration methods on various noises

Noise	Mean	Median	Gaussian	Wiener	Modified Wiener
Gaussian	18.1445	16.5898	19.2459	17.5559	18.2747
Poisson	22.3117	22.3462	20.7104	25.0223	22.318
Salt and Pepper	21.2359	22.4474	20.4513	19.8091	22.355
Speckle	21.628	20.9377	20.5515	22.938	21.4071
White	18.1445	20.3876	20.3686	21.1152	21.1168

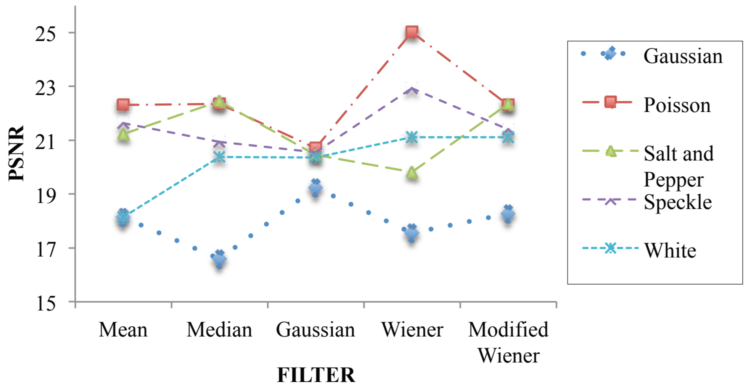


Figure 9. Performance of various filters based on PSNR

Linear filters tend to blur edges and other fine details of an image whereas non-linear filters can preserve edges and they are very effective at removing impulsive (salt and pepper) noise. Wiener filter is linear spatial filter, which is adaptive to the local variance. When the variance is small, its performance is smoother and vice versa, i.e. variance is indirectly proportional to smoothness. A single pixel with an unrepresentative value can influence the mean value of all the pixels in its neighbourhood significantly. The wiener filter especially for large windows causes dilation of edges and small peaks due to the mean computation, whereas the modified wiener preserves unaltered edges by computing the median value in the filtration process. The correlation coefficient between filtered image and the original image is computed and the results are shown in Table 2 and Figure 10.

Table 2
Correlation coefficient values between filtered and the original image

Noise	Mean	Median	Gaussian	Wiener	Modified Wiener
Gaussian	0.8248	0.7862	0.8796	0.8025	0.8404
Poisson	0.9367	0.937	0.9076	0.9668	0.9367
Salt and Pepper	0.9178	0.9385	0.9035	0.8854	0.9373
Speckle	0.9254	0.9132	0.9045	0.9452	0.9222
White	0.9083	0.901	0.9014	0.9151	0.9155

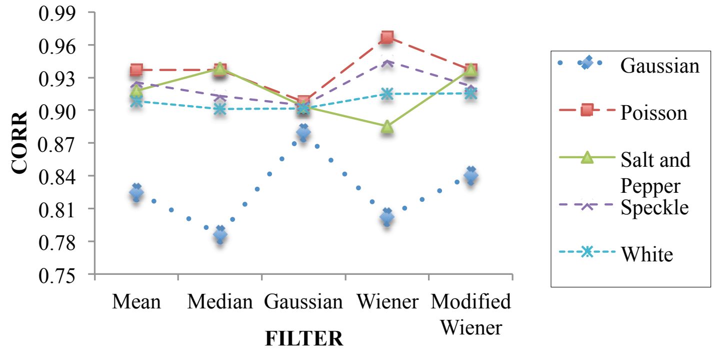


Figure 10. Performance of various filters based on CORR

Based on the results, it is found that the Mean and Gaussian filters are good at removing the Poisson noise but these techniques blur the image affecting the feature localisation. From the observations of PSNR value and the Correlation coefficient, it is clearly understood that a single filter cannot be used for various noise models in remote sensing images. The best filter for each noise model is thus found based on performance metrics, such as Peak signal to Noise Ratio and Correlation Coefficient. It is shown in Table 3.

Table 3
Image noise and suitable filter

Noise Model	Best Filter
Gaussian	Gaussian, Modified Wiener Filter
Poisson	Wiener, Median Filter, Modified wiener Filter
Salt and Pepper	Median, Modified Wiener Filter
Speckle	Wiener, Mean Filter
White	Modified Wiener, Wiener Filter

The Landsat images of Lake Turkana, Huang he Delta (Yellow River), Capecod USA obtained from the US Geological Survey and images from Earth Observation remote pixel dataset are used as test images for analysing the performance of various filters. It clearly shows the proposed modified wiener filter performs invariably better in most of the noise models.

CONCLUSION

The performance of various noise models and filtering techniques has been analysed for image enhancement and restoration. The similarity metrics such as peak signal to noise ratio and correlation coefficient are computed for all the filtered images on various noise models. The results show that a filter has to be chosen based on the application and type of data required for further processing in image analysis. The proposed modified wiener filter yields better performance compared with other linear and non-linear filters on various satellite images. The edges are well preserved by the use of median operator in modified wiener filter. However, the computational complexity of the image reconstruction based on modified wiener filter need to be further studied. The resultant filtered images can be used to investigate the spatiotemporal changes that have occurred in recent decades using remote sensing technology.

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