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Design of Efficient Adaptive Image Filters to suppress Salt and Pepper Noise

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ABSTRACT

Image processing technology is amongst the most rapidly growing technologies today, having its applications in various aspects of business. The massive production of digital images in the communication world has led to the need for efficient image restoration methods. Unlike conventional linear digital filters, adaptive digital filters are used to overcome the problem of removing noise in certain practical applications where the statistical characteristics of input and noise are normally unknown or can't be found out by fixed coefficient digital filters. The aim of this paper is to explain the concept of noise which leads to the need for developing filters and to design efficient adaptive local noise filter and adaptive LMS filter in their operation of demising low density salt and pepper noise.

Keywords: *Image processing, salt and pepper noise, adaptive filters, LMS adaptive filter, local noise adaptive filter.*

1. INTRODUCTION

To produce a visually high quality image, image restoration or demising is required which involves the manipulation of the image data resulting into a noise free image. An image can be degraded or corrupted due to various reasons like - improper opening of the shutter, atmospheric disturbances, misfocussing, motion between camera and object etc [1]. In order to suppress noise and improve image quality, it is necessary to do the de-noising of an image. The area has received steady attention since the 1960s and techniques for its solution continue to be proposed till date. Huang et al. [2] have proposed a 2-D median filtering that is based on sorting and updating gray level histogram of the picture elements in the window. Kundu et al., [3] have proposed a new approach of removing impulse noise from images using a mean filter. This filtering scheme is based on replacing the central pixel value by the general mean of all pixels inside a sliding window. Another filter known as signal adaptive median filter has been developed [4] that performs better than other nonlinear adaptive filters for different kinds of noise. On the similar lines various research and analyses papers have also been written at different points of time in history on this field. K.N. Platanioti et al., [5] have analyzed various filters for multichannel image processing. Huipin Zhang et al., [6] have proposed an adaptive threshold estimation method for demising an image. On similar lines of research in this paper an attempt has been made to throw detailed light on the subject of noises affecting images which gives birth to the need for developing demising techniques in form of filters with special focus on adaptive filters.

2. IMAGE PROCESSING

Image processing is a scientific method of converting an image into a digital form and thereafter performing some operations on it, in order to get an enhanced image or to extract some useful information from it. Most image-processing techniques involve treating the image as a two-dimensional signal and applying standard signal-processing techniques to it [7].

2.1 Image Processing Broadly Includes the Following Three Steps

- Importing the image with an optical scanner or by digital photography;
- Analyzing and manipulating the image which includes data compression and image enhancement and spotting patterns that are not to human eyes like satellite photographs;
- Output is the last stage in which the result can be an altered image or a report that is based on image analysis.

3. TYPES OF NOISE AND THEIR EFFECT ON IMAGE

Image noise is the random variation of brightness or color information in images produced by the sensor and circuitry of a scanner or digital camera [1]. Image noise is considered as an undesirable by-product of image capture. The magnitude of 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. Noise is caused by the environment around us. Therefore it is important to restore the images to their original features by removing the noise. In order to remove the noise someone has to know the noise itself so that it would be easy to remove it.

Noise in an image is a serious problem. The noise could be AWGN (additive white Gaussian noise), SPN (salt and pepper noise) or a mixed noise. Efficient suppression of noise in an image is a very important issue. Demising finds extensive applications in many fields of image processing. Conventional techniques of image demising using linear and nonlinear techniques have already been reported and sufficient literature is available in this area and has been already reviewed. Recently, various nonlinear and adaptive filters have been suggested for the purpose. The objectives of these schemes are to reduce noise as well as to retain the edges and fine details of the original image in the restored image as much as

possible. However, both the objectives conflict each other and the reported schemes are not able to perform satisfactorily in both aspects. Hence, still various research workers are actively engaged in developing better filtering schemes using latest signal processing techniques.
The types of noises are as follows:-

3.1 Uniform 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, but it will be signal independent if other noise sources are big enough to cause dithering, or if dithering is explicitly applied. The gray level values of the noise are evenly distributed across a specific range [8]. The PDF of this kind of noise can be depicted as follows:-

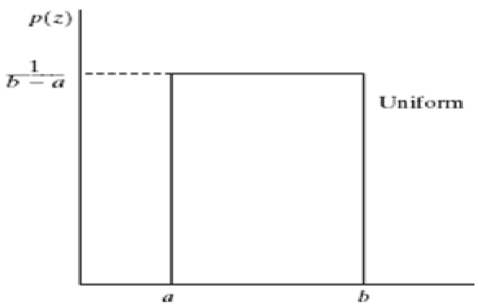

Fig 1: PDF of uniform noise

$$p(z) = \begin{cases} \dfrac{1}{(b-a)} & if\ a \le z \le b \\ 0 & otherwise \end{cases} \tag{1.1}$$

$$\mu = (a+b)/2 \tag{1.2}$$

$$\sigma^2 = (b-a)^2/12 \tag{1.3}$$

Where, 'z' is the Uniform random variable representing noise, 'μ' is the mean, and 'σ^2' is the variance of Uniform noise.

3.2 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 is caused by analog-to-digital converter errors, bit errors in transmission, etc. The PDF of this kind of noise is as follows:-

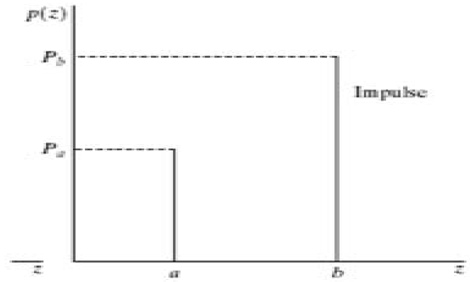

Fig 2: PDF graph of Impulse Noise

$$p(z) = \begin{cases} p_a & for \quad z = a \\ p_b & for \quad z = b \\ 0 & otherwise \end{cases} \tag{1.4}$$

where, 'z' is the random variable representing noise.

3.3 Gaussian Noise

Gaussian noise is one type of noise which is evenly distributed over the signal. This means that each pixel in the noisy image is the sum of the true pixel value and a random Gaussian distributed noise value [1, 8]. As the name indicates, this type of noise has a Gaussian distribution, which has a bell shaped probability distribution function. Gaussian noise is the noise which can be defined by the probability density function of the normal distribution (also known as Gaussian distribution). The noise function acquires the values of the Gaussian distribution function. Gaussian noise is additive in nature i.e. the Gaussian distributed noise values gets added to the intensity values of the image.

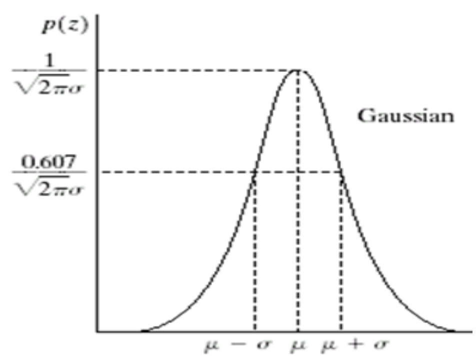

Fig 3: PDF graph of Gaussian Noise

$$p(z) = \frac{1}{\sqrt{2\pi\sigma}} e^{-(z-\mu)^2/2\sigma^2} \tag{1.5}$$

Where, 'z' is the Gaussian random variable representing noise, 'μ' is the mean, 'σ' is standard deviation and 'σ^2' is the variance of Gaussian noise.

3.4 Rayleigh Noise

Radar range and velocity images typically contain noise that can be modeled by the Rayleigh distribution. The PDF function of Rayleigh noise is given by:-

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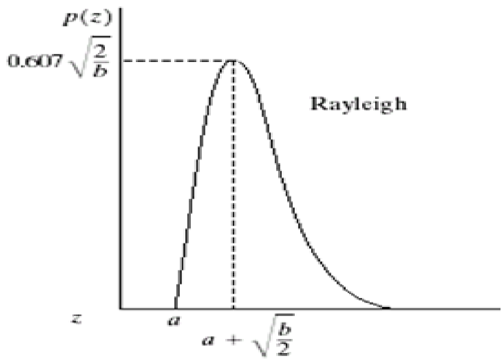

Fig 4: PDF graph of Rayleigh Noise

$$p(z) = \begin{cases} \frac{2}{b}(z-a)e^{-(z-a)^2/b} \\ \\ 0 \end{cases} \qquad (1.6)$$

Where, 'z' is the random variable representing noise.

4. ESSENCE OF FILTERING AN IMAGE

Filtering in an image processing is a basic function that is used to achieve many tasks such as noise reduction, interpolation, and re-sampling. Filtering image data is a standard process used in almost all image processing systems. The choice of filter is determined by the nature of the task performed by filter and behavior and type of the data. Filters are used to remove noise from digital image while keeping the details of image preserved is a necessary part of image processing. There are two kinds of filtering techniques- linear and non linear. One of the many kinds of available filters is adaptive filters and the following section proceeds to discuss the same as it is the core area of study undertaken by the author.

4.1 Adaptive Filters

An adaptive filter is a self-modifying digital filter that adjusts its coefficients in order to minimize an error function. The error function is a distance measurement between the reference or desired signal and the output of the adaptive filter [9].

The behavior of the Adaptive filters changes with the statistical characteristics of the image inside the filter window. Therefore the performance of Adaptive filters is much better in comparison with the non-adaptive filters. But the improved performance is at the cost of added filter complexity.

An adaptive filter does a better job of demising images compared to the averaging filter. Adaptive filters are capable of demising non-stationary images, that is, images that have abrupt changes in intensity. Such filters are known for their ability in automatically tracking an unknown circumstance or when a signal is variable with little a priori knowledge about the signal to be processed. In general, an adaptive filter iteratively adjusts its parameters during scanning the image to match the image generating mechanism. This mechanism is more significant in practical images, which tend to be non-stationary.

5. DESIGN METHODOLOGY

The present day state-of-art technology offers very high quality photo sensors, high quality electronic circuitry, e.g., system on chip (SOC), and high quality channel as well [10]. Therefore, the noise level has drastically reduced. The filters that are quite efficient at high noise levels don't perform so well at low noise levels. Therefore, it is very important to design and develop highly efficient image filters that suppress low power noise quite effectively. Therefore, the objective of this research paper is to develop some novel linear adaptive digital image filters for efficient noise suppression under low and very low noise power conditions. Adaptive filters extend the notion of linear filters by allowing for coefficients which change according to local image properties.
To overcome the shortcomings of fixed filters such as mean and median filters, adaptive filters are designed that adapt themselves to the changing conditions of signal and noise. The two broad categories of adaptive image filters proposed for efficient noise suppression are:

(i) Adaptive Local Noise Filter (ALNF)
(ii) Adaptive LMS Filter (ALF).

(i) Adaptive Local Noise Filter (ALNF)

Adaptive filter is performed on the degraded image that contains original image and noise. The mean and variance are the two statistical measures that a local adaptive filter depends with a defined m x n window region as expressed by the equation (1.7) below:

$\hat{f}(x, y) = g(x, y) - (\sigma^2_\eta/\sigma^2_L)\,[g(x,y) - m_L]$ (1.7)

Where, σ^2_L – is local variance of the local region,
m_L - is the Local Mean, σ^2_η – is variance of overall noise and g (x, y) – is the pixel value at the position (x, y).

Procedural Steps

1. Define a window of size m x n
2. Pad the noise matrix with zeroes
3. Compute the local mean and local variance for window size m x n
4. Compare noise variance and local variance i.e (if (noise variance > local variance) then local variance = noise variance.
5. Compute the convolution of the ratio of noise variance to local variance and difference of original image matrix and local mean.
6. The final filtered image is obtained by subtracting the convolution result from the original image.
7. Calculation of different image quality metrics.

(ii) Adaptive LMS Filter (ALF)

The LMS (Least Mean Square) algorithm is an important member of the family of stochastic gradient algorithms. A stochastic gradient method differs from a deterministic gradient approach such as steepest descent method [10].

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Procedural Steps

1. Define a window, W, of size m x n and scan it over the entire image.
2. Obtain the residual matrix, W_r, by subtracting the mean, μ, of this window from the elements in the window.

   $W_r = W - \mu$ (1.8)

3. Compute a weighted sum, $\tilde{z}$.
4. Replace the centre element of the window by the sum of weighted sum, $\tilde{z}$, and the mean, μ.
5. Now, calculate for the next iteration, by shifting the window over one pixel in row major order and correspondingly modify the weight matrix. Thus, the resultant modified pixel value, z, is given as:

   $z = \tilde{z} + \mu$ (1.9)

6. The deviation e is computed by taking the difference between the center value of the residual matrix and the weighted sum as in equation (1.10).

   $e = W_r - \tilde{z}$ (1.10)

7. Update the weight matrix with each iteration by reducing the minimum mean squared error.
8. Continue the process until the window covers the entire image.

Finally calculate the various image quality metrics.

5.1 Measures of Image Quality

There are various metrics used for objective evaluation of an image. Some of them are mean squared error (MSE), root mean squared error (RMSE) and peak signal to noise ratio (PSNR).

Let the original noise-free image, noisy image, and the filtered image be represented by X (m, n), Y(m, n), and $\tilde{X}$(m, n), respectively. Here, m and n represent the discrete spatial coordinates of the digital images.

Let the images be of size M×N pixels, i.e. m=1,2,3,…,M, and n=1,2,3,…,N. Then, MSE and RMSE are defined as:

$$MSE = \frac{\sum_{m=1}^{M}\sum_{n=1}^{N}(\widetilde{X}(m,n) - X(m,n))^2}{M \times N} \quad (1.11)$$

$$RMSE = \sqrt{MSE} \quad (1.12)$$

The PSNR is defined in logarithmic scale, measured in dB. It is a ratio of peak signal power to noise power. The image metric PSNR is defined as:

$$PSNR = 10.\log_{10}(S^2 / MSE) \quad (1.13)$$

Where, S is the size of the image.

The image metrics: MSE, RMSE, PSNR are used in this thesis to evaluate the performance of a digital image filter.

6. RESULTS AND DISCUSSIONS

In essence, it may be stated, in general, that:

(a) (SPN of density below **0.1%** may be regarded as **very low** noise condition.
(b) SPN of density **0.1-1%** may be regarded as **low noise** condition.
(c) SPN of density **0.1-1%** may be regarded as **low noise** condition.
(d) SPN of density **3-10%** may be regarded as **high noise** condition.

Therefore, here, the proposed filters are tested using SPN density below 1%. The figurative results of both the filters viz, (i) Adaptive local noise filter (ALNF) and (ii) Adaptive LMS filter (ALF) are depicted below.

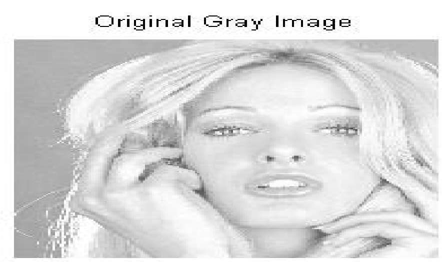
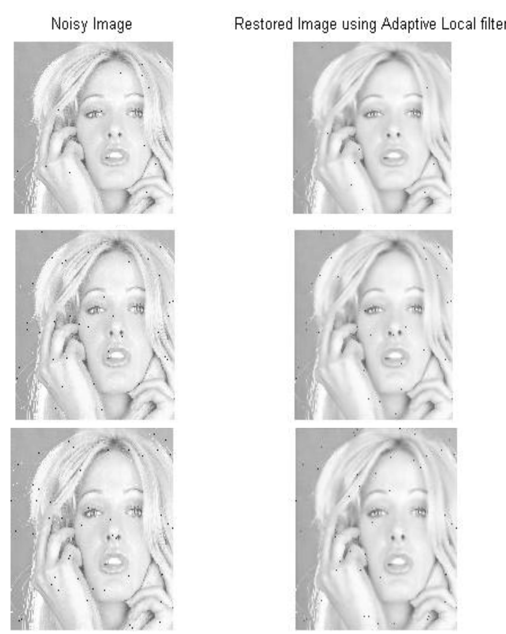


Fig 5: Shows Grayscale noise free original image

6.1 Results of Adaptive Local Noise Filter



(a)

(b)

(c)

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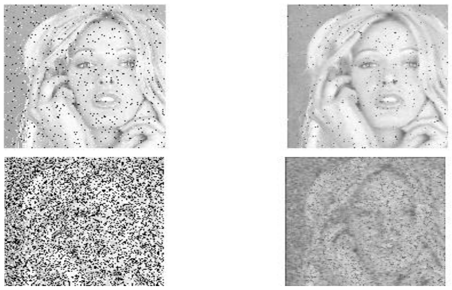
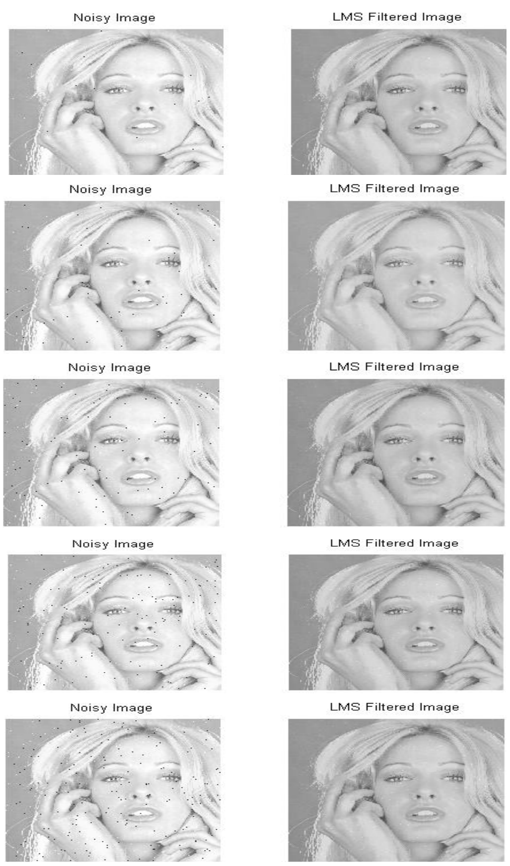


(d)

(e)

Fig 6: Shows filtered images when noisy images are corrupted with SPN of noise variance (a) 0.001, (b) 0.003, (c) 0.005, (d) 0.05, (e) 0.5

6.2 Results of Adaptive LMS Filter



(a) (b) (c) (d) (e)

Fig 7: Shows filtered images when noisy images are corrupted with SPN of noise variance (a) 0.001, (b) 0.003, (c) 0.005, (d) 0.007, (e) 0.01

Table 1: Results for Adaptive local noise filter

SPN noise density	MSE	RMSE	PSNR
0.0005	49.3307	7.0236	45.7198
0.001	56.7825	7.5354	45.4143
0.002	69.2652	8.3226	**44.9828**
0.003	78.2136	8.8438	44.7190
0.005	92.9193	9.6395	44.3449
0.009	506.3015	22.5011	**34.6428**
0.5	1.0075e+004	100.3751	28.1485
01	8.3624e+003	91.4464	**34.5737**

Table 2: Results for Adaptive LMS filter

SPN noise density	MSE	RMSE	PSNR
0.0005	4.5145e+004	212.4734	30.9124
0.001	4.5135e+004	212.4508	30.9128
0.002	4.5129e+004	212.4356	30.9131
0.003	4.5114e+004	212.4005	30.9138
0.004	4.5095e+004	212.3556	30.9148
0.005	4.5091e+004	212.3467	30.9149
0.006	4.5066e+004	212.2881	30.9161
0.007	4.5056e+004	212.2639	30.9166
0.008	4.5047e+004	212.2431	30.9171

Tabular representation of these experimental results based on various parameters like PSNR (peak signal to noise ratio), MSE (mean square error) and RMSE (root mean square error) are presented as above. Moreover, when the results of these two filters are compared with those of Simple Median Filter (SMF) and Adaptive Median Filter (AMF), it is observed ALNF has the best PSNR compared to all. The table below shows the same.

Table 3: Comparing the PSNR of ALNF, ALF, SMF & AMF

SPN Noise Density	PSNR			
	ALNF	ALF	SMF	AMF
0.001	45.4143	30.9128	44.8760	38.3822
0.002	44.9828	30.9131	44.8778	38.3608
0.003	44.7190	30.9138	44.8761	38.3433
0.004	44.4975	30.9148	44.8771	38.3326
0.005	44.3449	30.9149	44.8762	38.3146
0.006	44.1063	30.9161	44.8729	38.2904
0.007	43.8161	30.9166	44.8736	38.2848
0.008	43.8161	30.9171	44.8731	38.2667
0.009	34.6428	30.9172	44.8730	38.2413
0.01	34.5448	30.9176	44.8702	38.2267

7. CONCLUSION AND FUTURE SCOPE

In this paper various methods and importance of image processing are explained. One of the image processing techniques, the digital image processing, is discussed laying special focus on image restoration. Efforts are made to research the efficiency of linear adaptive filters to suppress Salt and Pepper Noise. From the experimental and mathematical results it is transpired that for salt and pepper noise, the adaptive local noise filter is optimal compared to adaptive LMS filter. It produces the maximum PSNR along with preserving the edges and fine details for the output image in cases where the image is corrupted with low density salt and pepper noise i.e 0.1% to 1%. However it is worth noting that research in the field of image demising is not yet fully explored. There is sufficient scope to develop very good filters. For future research, it would be good for researchers to work further on the comparison of the demising techniques and they can take this research forward to explore the possibility and usage of ALNF on an image corrupted with other kind of noises.

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