Hybrid Wiener Median Filter

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ABSTRACT *Images often get corrupted with noise during the process of their acquisition and transmission. Predominant among the noises are the salt-and-pepper noise, Gaussian noise and the multiplicative noise. A wide variety of algorithms have been proposed in the literature for reducing or eliminating these noises. Each algorithm has its own merits and limitations. This paper proposes a hybrid filter which exploits the features of both Wiener filter and the Median filter to reduce Gaussian noise in a number of benchmark images. The Median filter, a smoothing filter, is effective at removing noise in smooth patches or smooth regions of a signal, but adversely affect edges. On the other hand, the Wiener filter uses the frequency domain approach and acts as an all pass filter. It tries to build an optimal estimate of the original image by enforcing a minimum mean-square error constraint between estimate and the original image by enhancing the edges. This hybrid technique produces satisfactory results as compared with other techniques in terms of PSNR.*

Keywords: *Wiener Filter, Median Filter, PSNR, Gaussian Noise, Mean-squared error.*

I. INTRODUCTION

The main source of noise[1]-[7] in digital images arises during image acquisition and transmission. The performance of image sensors is dependent on a variety of reasons including environmental conditions existing during the process of image acquisition or by the quality of the sensing element. The sensor temperature and the light levels are predominant factors that affect the amount of noise in the image while acquiring images using a CCD camera. During transmission, interference in the channel is a major cause for noise induction in the image.

Hence, it is seen that noise can badly degrade the quality of an image and cause the loss of vital details from the acquired image. This necessitates the elimination of noise in the images as a pre-processing step before certain operations including edge detection, image segmentation, image segmentation and object recognition.

Gaussian noise[7] has a significant role in degradation of images obtained after transmission. Gaussian noise is an additive noise. The noisy pixels in an image corrupted with Gaussian noise is formed by the addition of a numerical value from a zero mean Gaussian distribution. Such noise can be suppressed using a wide variety of linear and non-linear filters. A wide variety of linear and non-linear techniques have been proposed in the literature including Median filter[8]-[11], Arithmetic filter[7], Gaussian Filter[7], Wiener Filter[12]-[15] and the Wavelet transform approach[1]-[3]. Conventional linear filters, such as arithmetic mean filter and Gaussian filter remove noise effectively but blur edges. The Wiener filter is the mean square error-optimal stationary linear filter for images degraded by additive noise and blurring. However a common drawback of the practical use of this method is the fact that they usually require some 'a priori' knowledge about the spectra of noise and the original signal. This information is essential for choosing the optimal values of both the parameter and the threshold values. Such information is often not available in real time applications. Also Wiener filter experiences uniform filtering throughout the image, with no allowance for changes between low and high frequency regions, resulting in unacceptable blurring of fine detail across edges and inadequate filtering of noise in relatively flat areas. Since the goal of the filtering action is to cancel noise while preserving the integrity of edge and detail information, nonlinear approaches generally provide more satisfactory results than linear techniques.

This paper proposes a simple and efficient hybrid filter which exploits the properties of both Median and Wiener filter for removing noise in images corrupted by Gaussian noise. The Median filter, a smoothing filter, is effective at removing noise in smooth patches or smooth regions of a signal, but adversely affect edges. On the other hand, the Wiener filter tries to build an optimal estimate of the original image by enforcing a minimum mean-square error constraint between estimate and the original image by enhancing the edges. Here, by taking into account local statistics, the local constraints are defined so that over smoothness of recovered image is avoided.

The rest of the paper is arranged as follows. The proposed methodology is discussed in section II while the simulation results are depicted in section III. The conclusion is presented in section IV.

II. PROPOSED METHODOLOGY

This is a hybrid of the spatial and the transform method for reducing Gaussian noise. This method uses Wiener filter along with the median filter for reducing Gaussian noise. The median filter is a spatial method of reducing Gaussian noise. An *(n* x *n)* filtering window is applied around each noisy pixel. However, to make this possible for the boundary pixels, the image has to be padded on all sides by some padding method. The symmetrical padding method has been adopted here. Odd sized window is preferred as it provides better results for median estimation. For a (3x3) filtering window, median is found from the nine neighboring pixels using equation 1. The median filter helps in reducing noise at low frequency regions.

$$M(i,j)=\text{median}[(X(i-1,j-1), X(i-1,j), X(i-1,j+1), X(i,j-1),X(i,j), X(i,j+1), X(i+1,j-), X(i+1,j), X(i+1,j+1)] \quad (1)$$

The Wiener Filter is a frequency domain approach and acts as an all pass filter. It tries to build an optimal estimate of the original image by enforcing a minimum mean-square error constraint between estimate and the original image. The Wiener filter is an optimum filter. The objective of a Wiener Filter is to minimize the mean square error. A Wiener filter has the capability of handling both the degradation function as well as noise. [6]

The Wiener Filter incorporates both the degradation function and statistical characteristics of noise into the restoration process. It is based on considering images and noise as random variables, and the objective is to find an estimate ***Y(i,j)*** of the uncorrupted image *f*(i,j) in spatial domain (*i,j*) such that the mean square error between them is minimized. This error measure is given by

$$e^2 = E\{(f(i,j) - Y(i,j))^2\} \quad (2)$$

where E{.} is the expected value of the argument. It is assumed that the noise and the image are uncorrelated; that one or the other has zero mean; and that the intensity levels in the estimate are a linear function of the levels in the degraded image. Based on these conditions, the minimum of the error function in equation 2 is given in the frequency domain (u,v) by the expression given below in equation 3.

$$\hat{Y}(u,v) = \left[\frac{H^*(u,v)S_f(u,v)}{S_f(u,v)|H(u,v)|^2 + S_\eta(u,v)}\right]G(u,v)$$

$$= \left[\frac{H^*(u,v)}{|H(u,v)|^2 + S_\eta(u,v)/S_f(u,v)}\right]G(u,v)$$

$$= \left[\frac{1}{H(u,v)} \mathrm{x} \frac{H^*(u,v)S_f(u,v)}{|H(u,v)|^2 + S_\eta(u,v)/S_f(u,v)}\right]G(u,v) \quad (3)$$

where
$H(u,v)$ = degradation function
$H^*(u,v)$ = complex conjugate of $H(u,v)$
$|H(u,v)|^2 = H^*(u,v)\, H(u,v)$
$S_\eta(u,v) = |N(u,v)|^2$ = power spectrum of the noise
$S_f(u,v) = |Y(u,v)|^2$ = power spectrum of the undegraded image

This is based on the fact that the product of a complex quantity with its conjugate is equal to the magnitude of the complex quantity squared. The filter which consists of the terms inside the bracket is commonly referred to as the minimum mean square error filter or the least square error filter. [6]

The procedure for reducing Gaussian noise using the hybrid technique is divided into two stages:

Stage 1: Determination of the median of the neighborhood of each pixel of the image using a (3x3) filtering window to obtain the intermediate denoised image at different noise levels.

Stage2: Application of the Wiener filter to the denoised image of stage 2 to get the final denoised image using equation 3

III. EXPERIMENTAL RESULTS

The performance of this technique is measured both quantitatively and qualitatively using PSNR and visual observations respectively for a wide range of noise levels varying from $\sigma = 5$ to 50 in steps of 5.

TABLE 1

Comparison of Restoration Results of proposed method, Hybrid Wiener-Median Filter (HWMF) in PSNR (dB) for image 'Lena'

Noise (σ)→ / Filtering technique↓	5	10	15	20	25	30	35	40	45	50
INPUT PSNR	34.13	28.13	24.61	22.12	20.20	18.70	17.41	16.36	15.42	14.60
Adaptive Window Median Filter (3x3) (AWMDF)	34.88	32.58	30.44	28.58	27.01	25.67	24.52	23.49	22.53	21.65
Adaptive Window Mean Filter (3x3) AWMF	34.03	32.80	31.33	29.85	28.52	27.25	26.22	25.23	24.39	23.59
WIENER FILTER	37.10	34.07	31.36	29.15	27.35	25.88	24.63	23.58	22.69	21.90
Hybrid Wiener Median Filter (HWMF)	34.16	32.95	31.56	30.26	29.04	27.88	26.76	25.84	24.93	24.14

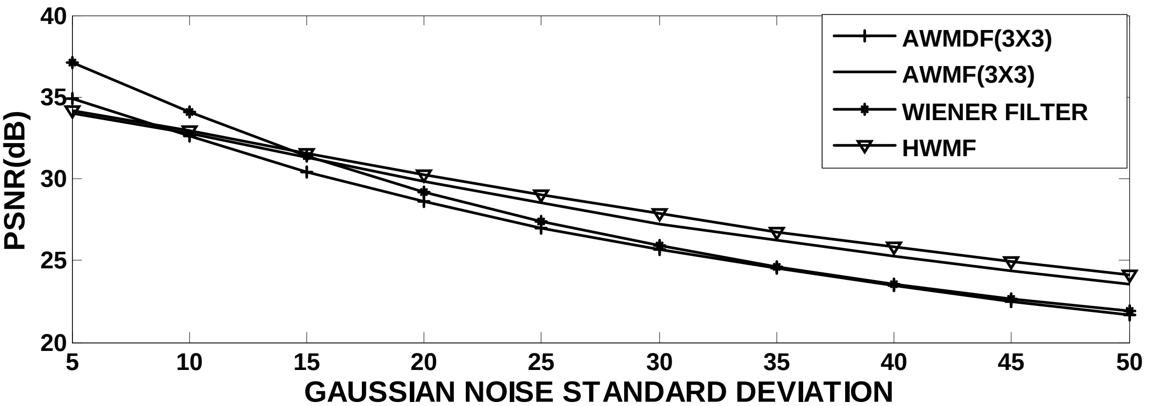

Fig. 1. Restoration Results for 'Lena' Image

Table 1 enlists the restoration result in PSNR (dB) of the hybrid method for 512x512 grayscale image 'Lena' corrupted by varying levels of Gaussian noise. Fig. 1 and Fig. 2 shows the restoration results of the various filters graphically and quantitatively respectively.

(a) (b)

(c) (d)

Fig. 3 Restoration Results for σ=50 for Various Methods
(a) AWMDF (3X3) (b) AWMF(3X3) (c) Wiener Filter (d) HWMF

It can be seen that the HWMF algorithm performs significantly better than the median, mean and Wiener filter at high noise levels. This can be seen both at the quantitative and qualitative levels.

This hybrid Median Wiener filter proposed in this section can reduce the Gaussian noise efficiently while preserving the edges to some extent at high noise levels. The simulation results demonstrate that the proposed approach performs better than many methods at high noise levels.

IV. CONCLUSION

A hybrid of the spatial and the transform method for reducing Gaussian noise has been proposed in this paper. The adaptive median filter has been used along with the Wiener filter. The median filter is very effective in the low frequency regions. The Wiener filter, also a smoothing filter, when used along with median filter helps in reducing noise for high values of Gaussian noise variances. However, at low levels of Gaussian noise variation, the results are not satisfactory. Future work should aim at improving the PSNR at low levels of Gaussian noise and reducing the processing time.

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