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Research Article

Analysis of Wavelet Denoising with Different Types of Noises

Kishan Shivhare[†*] and Gaurav Bhardwaj[†]

[†]ECE Department, RJIT BSF Academy, Tekanpur, Gwalior, M.P., India

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Abstract

There are several types of noises those affect quality of an image such as Salt & pepper noise, Poisson noise, Gaussian noise, Speckle noise etc. Wavelet is a powerful tool for denoising a variety of signals. Here an image of a college building has been taken for denoising purpose with the help of HAAR Transform. The noisy image is first decomposed into five levels to obtain different frequency bands. Then first soft and hard thresholding methods are saperately used to remove the noisy coefficients by fixing the optimum thresholding value at 0.15 and then both of thresholdings are used in hybrid manner. In this paper, analysis of a colored image is carried out with four different noises at zero mean and at 0.02 variance that are applied on the image to produce noisy images. In order to enhance the quality of the noisy images, performance parameters of denoised images must be estimated. The comparison between different denoised image is taken in terms of MSE (mean square error), PSNR (peak signal to noise ratio), RMSE (root mean square error), SNR (signal to noise ratio) and SSIM (structural similarity index).

Keywords: *Salt & Pepper noise, Speckle noise, Gaussian noise, Poisson noise, Discrete Wavelet Transform, Soft thresholding, Hard thresholding, SNR, PSNR, SSIM, MSE, RMSE.*

1. Introduction

An image is mostly affected by noise produced by the sensor and circuitry of a scanner or digital camera. The denoising process is to remove the noise with retaining and not distorting the quality of processed image. Denoising analysis of the images is done by using Discrete Wavelet Transform (DWT). The experiments are conducted on a building image (.jpg format).

Simple denoising algorithms which use DWT consist of three steps:

1) Discrete wavelet transform is adopted to decompose the noisy image and get the wavelet coefficients.
2) These wavelet coefficients are denoised with wavelet threshold.
3) Inverse transform is applied to the modified coefficients and get denoised image.

Thresholding is a simple non-linear technique which operates on one wavelet coefficients at a time. Each coefficient is thresholded by comparing threshold level. When a coefficient is smaller than threshold level then it is set to zero otherwise it is kept as it is or it is modified.

The wavelet transform is better than Fourier transform because it gives frequency representation of the signal at any given interval of time, but Fourier transform gives only the frequency- amplitude representation of the signal but the time information is lost.

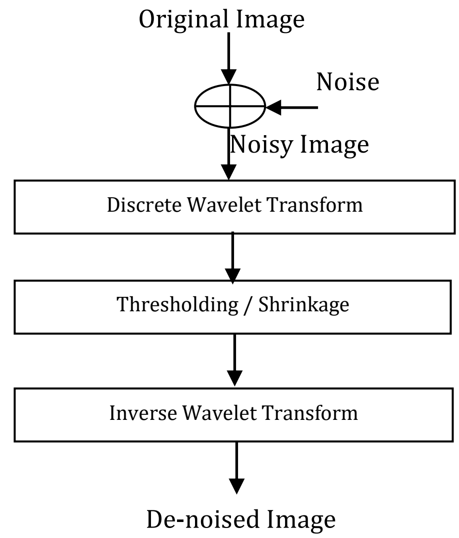


Fig.1 Image denoising based on Wavelet Transform

So we use Wavelet transform instead of the Fourier transform where we need time as well as frequency information at particular time. The fundamental idea behind wavelet coefficients is to analyze the signal at

*Corresponding author **Kishan Shivhare** is a M.Tech Student; **Gaurav Bhardwaj** is working as Assistant Professor

different scales or resolutions, which is called multiresolution. The most important feature of wavelet transform is that it allows multiresolution decomposition. The wavelet transform is good at energy compaction. The small coefficients are more likely due to noise and large coefficients are more likely due to important signal features. These small coefficients can be thresholded without affecting the significant features of the image.

Noise is a random variation of image Intensity and visible as small particles in the image. It may arise in the image as effects of basic physics-like photon nature of light or thermal energy of heat inside the image sensors. Here we are discussing about four types of noise and their effect on the image signal.

1) Gaussian noise
2) Speckle noise
3) Salt-and-pepper noise
4) Poisson noise

Gaussian noise is a statistical noise having a probability density function (pdf) equal to the pdf of the normal distribution, which is also known as the Gaussian distribution. This is an additive noise model in nature. Additive white Gaussian noise (AWGN) can be produced by poor quality image acquisition, noisy environment or internal noise in communication channels.

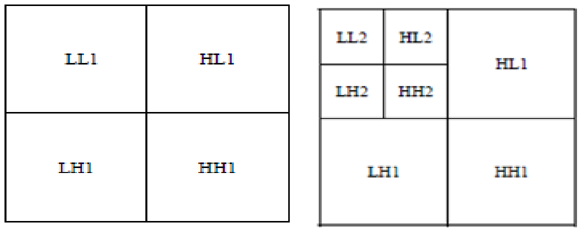
Speckle-noise is a granular noise in nature. It degrades the quality of the active radar, synthetic aperture radar (SAR), and medical ultrasound images. Speckle noise occurs due to random fluctuations in the return signal from an object in a RADAR system.

Salt-and-pepper noise is also called impulsive noise or spike noise. Any image which has been affected by salt and pepper noise shows dark pixels in bright area and bright pixels in dark area of the image. It has only two possible values, a high value and a low value. This noise occurs during analog-to-digital converter errors, bit errors in transmission.

Poisson noise or Shot noise is an electronic noise which is generated by a Poisson process. Shot noise follows the particle nature of light. Poisson or shot photon noise is the noise that occurs when the number of photons sensed by a sensor is not sufficient to provide detectable statistical information.

2. Discrete Wavelet Transform (DWT)

In Discrete Wavelet Transform signal energy is in the form of a small number of coefficients. DWT of noisy image if consist of small number of coefficients then would have high value of SNR and vice versa. Using inverse DWT, image is reconstructed by removing the coefficients with low SNR. Time and frequency components are simultaneously provided by Wavelet transform. When DWT is applied to noisy image, it is spreaded into four sub bands as shown in Figure 2(a). These sub bands are formed by separable horizontal and vertical filters. The coefficients which are represented as sub bands LH1, HL1, and HH1 are detail images while coefficients which are represented as sub band LL1 is approximation image. To obtain the next level of the wavelet coefficients the LL1 sub band is further decomposed as shown in Figure 2(b).



(a) One level (b) Two level

Fig.2 Image Decomposition by using DWT

As LL1 sub band provides the most like original picture that is why it is called the approximation sub band. It is obtained from low pass filtering in both directions. The other bands are called detail sub bands. The L and H filters as shown in Figure 3 are one dimensional low pass filter (LPF) and high pass filter (HPF) used for image decomposition. HL1 is called horizontal fluctuation as it comes from low pass filtering in vertical direction and high pass filtering in horizontal direction. LH1 is called vertical fluctuation as it comes from opposite to HL1. HH1 comes from high pass filtering in both the directions so it is called diagonal fluctuation. LL1 is further decomposed into 4 sub bands LL2, LH2, HL2 and HH2. The process is carried out until the fifth decomposition is reached. After L number of decompositions a total number of D(L) =3*L+1 sub bands are obtained. Therefore after 5 decompositions D(5) = 3*5+1 = 16 sub bands are obtained.

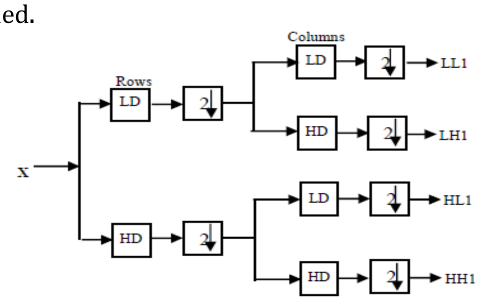


Fig.3 Wavelet Filter Bank Decomposition (One level)

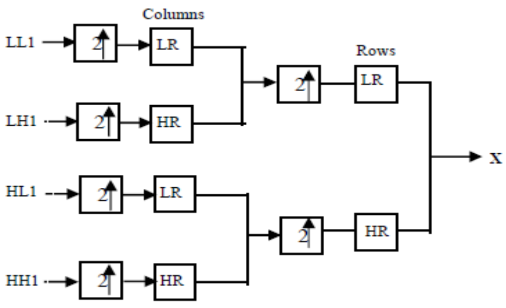


Fig.4 Wavelet Filter Bank Reconstruction (One level)

A reverse process is shown in figure 4 which is used to reconstruct the decomposed image. Here, the L and H filters represent low pass reconstruction and high pass reconstruction filters respectively.

3. Wavelet Thresholding

Thresholding technique operates on wavelet coefficients. It uses one of the wavelet coefficients at a time. In this process the coefficient which is smaller than the threshold value is set to zero otherwise the coefficient is kept or may be modified.

If the coefficient has small value then it carries more noise than a large valued coefficient. While if it has large value then coefficient carries more signal information than small valued coefficients. Therefore noise coefficients or small valued coefficients below a certain threshold value are replaced by zero and an inverse wavelet transform may lead to a reconstruction that has lesser noise.

Firstly wavelet analysis of a noisy image up to level N is done with thresholding of the each detail coefficients from level 1 to N and then signal is synthesized by using the altered detail coefficients from level 1 to N and approximation coefficients of level N.

There are two types of thresholding;

1) Hard thresholding technique
2) Soft thresholding technique

3.1 Hard thresholding technique

Hard thresholding shrinks the coefficients which have magnitudes below the threshold level, and leaves the rest of the coefficients unchanged. To suppress the noise we apply hard thresholding on each wavelet coefficients:

$$F(X) = X \times I(|X| > t)$$

Here 't' is a certain threshold and x is the coefficient.

$$t = \sqrt{\left(\frac{2\sigma^2 \log(n)}{n}\right)}$$

Where 'n' is the length of the input vector and σ^2 is the variance of the noise.

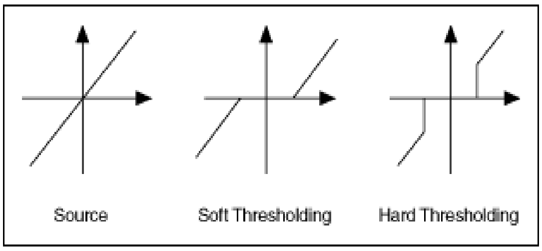


Fig.5 Hard and Soft Thresholding

3.2 Soft thresholding technique

Soft thresholding technique extends hard thresholding technique by shrinking the magnitude of the remaining coefficients by 't' factor and producing a smooth rather than abrupt transition to zero.

$$S(x) = \text{sign}(x)(|x| - t)\, I(|x| > t)$$

4. Performance Parameters

For comparing original building image with different denoised images, we calculate following parameters:

1) Mean Square Error (MSE): The MSE is the cumulative square error between the synthesized image and the original image defined by:

$$\text{MSE} = \sum_0^{m-1} \sum_0^{n-1} ||f(i,j) - g(i,j)||^2$$

Where 'f' is the original image and 'g' is the synthesized image. MSE should be as low as possible.

2) Peak signal to noise ratio (PSNR): PSNR is the ratio between maximum possible power of a signal and the power of distorting noise which affects the quality of the original signal. It is defined by:

$$\text{PSNR} = \frac{20 \log_{10}(\text{MAX}_F)}{\sqrt{\text{MSE}}}$$

Where MAX_F is the maximum signal value that exists in our original image. PSNR should be as high as possible.

3) Root mean square error (RMSE): It measures of the differences between value predicted by a model or an estimator and the values actually observed. It is the square root of mean square error. RMSE should be as low as possible.

$$\text{RMSE} = \sqrt{\text{MSE}}$$

4) Structural Similarity Index (SSIM): It is a method for measuring the similarity between two images. The SSIM measure the image quality based on an initial distortion-free image as reference.

$$\text{SSIM} = \frac{(2\mu_X\mu_Y + C_1)(2\sigma_{XY}C_2)}{(\mu_X^2 + \mu_Y^2 + C_1)(\sigma_X^2 + \sigma_Y^2 + C_2)}$$

Where: μ_x is average of x; μ_y is average of y;
σ_X^2 is variance of x; σ_Y^2 is variance of y;
σ_{XY} is covariance of x and y;

$C_1 = (k_1L)^2$ and $C_2 = (k_2L)^2$ are two variables to stabilize the division with weak denominator. L is the dynamic range of the pixel-values $k_1 = 0.01$ and $k_2 = 0.03$ by default.

5) Signal to noise ratio (SNR): Signal-to-noise ratio is defined as the power ratio between a signal (meaningful information) and the noise (unwanted signal). It should be as high as possible.

$$SNR = \frac{P_{SIGNAL}}{P_{NOISE}}$$

5. Methodology

1) A building image has been taken for denoising purpose in Wavelet Toolbox in MATLAB. Four different noises (Salt and pepper, Speckle, Gaussian and Poisson) are added one by one in the original image of dimensions 512x512 in .jpg format at zero mean and 0.02 variance. For denoising HAAR wavelet transform is applied on the noisy images of all the four different noises up to five levels. A constant threshold value is taken at these levels. Each coefficient of vertical, horizontal and diagonal details is thresholded using soft, hard and hybrid threshold by combining both hard and soft. As a result of inverse wavelet transform, we get these noise free images within vertical, horizontal and diagonal details.

2) Calculation of the performance parameters for analyse denoised images is performed in the terms as SNR, PSNR, SSIM, MSE and RMSE.

6. Result

(a)

(b)

(c)


(d)

(e)


(f)

(g)


(h)

(i)

(j)

(k)


(l)

(m)

(n)

(o)


(p)

(q) (r)

Fig.6 (a) Color Image, (b) Gray Image, (c) Image after adding Salt & Pepper noise, (d) Image after denoised by Soft threshold, (e) Image after denoised by Hard threshold, (f) Image after denoised by Hybrid threshold, (g) Image after adding Speckle noise, (h) Image after denoised by Soft threshold, (i) Image after denoised by Hard threshold, (j) Image after denoised by Hybrid threshold, (k) Image after adding Gaussian noise, (l) Image after denoised by Soft threshold, (m) Image after denoised by Hard threshold, (n) Image after denoised by Hybrid threshold, (o) Image after adding Poisson noise, (p) Image after denoised by Soft threshold, (q) Image after denoised by Hard threshold, (r) Image after denoised by Hybrid threshold

Table 1 Noises at zero mean and 0.02 variance and SNR

Noises (0,0.02)	SNR		
	Soft thresholding	Hard thresholding	Hybrid thresholding
Salt & Pepper	42.1310	42.2857	42.0995
Speckle	42.0791	42.2100	42.5175
Gaussian	42.3876	42.5216	42.0935
Poisson	42.1550	42.2972	42.1282

Table 2 Noises at zero mean and 0.02 variance and PSNR

Noises (0,0.02)	PSNR		
	Soft thresholding	Hard thresholding	Hybrid thresholding
Salt & Pepper	47.7958	47.9388	47.7576
Speckle	47.8234	47.9572	47.7908
Gaussian	47.7765	47.9065	47.7314
Poisson	47.8875	48.0296	47.8606

Table 3 Noises at zero mean and 0.02 variance and SSIM

Noises (0,0.02)	SSIM		
	Soft thresholding	Hard thresholding	Hybrid thresholding
Salt & Pepper	0.0170	0.0087	0.0118
Speckle	0.0127	0.2092	0.0106
Gaussian	0.0126	0.0106	0.0091
Poisson	0.0150	0.2217	0.0144

Table 4 Noises at zero mean and 0.02 variance and MSE

Noises (0,0.02)	MSE		
	Soft thresholding	Hard thresholding	Hybrid thresholding
Salt & Pepper	16334.3605	16926.6030	16216.2807
Speckle	16140.2191	16634.1630	16007.3208
Gaussian	17328.4246	17871.5007	16193.8067
Poisson	16424.9752	16971.3494	16323.7140

Table 5 Noises at zero mean and 0.02 variance and RMSE

Noises (0,0.02)	RMSE		
	Soft thresholding	Hard thresholding	Hybrid thresholding
Salt & Pepper	127.8059	130.1023	127.3432
Speckle	127.0442	128.9735	126.5200
Gaussian	131.6375	133.6843	127.2549
Poisson	128.1600	130.2741	127.7643

Conclusions

According to results generated in this paper, the Hard thresholding has good results in SNR and PSNR but Hybrid thresholding has less error results. Therefore Hybrid Thresholding can be used to get the more accurate results. Inspite of these the threshold value and the level of decomposition and reconstruction also play an important role in Wavelet denoising.

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