Edge Preserving Image Filtering Using Linear SURE and Wavelet Approach of SURE

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Abstract— This paper concentrates on developing a noise reduction method using a local linear model using the principle of Steins Unbiased Risk Estimator (SURE) along with the help of haar wavelet transform. Here, SURE is used as an estimate to reduce Mean Square Error. Control of images for performing various operations is an essential factor in this context. Hence there is an increased need to transform the image space into arithmetical domain. For the purpose of denoising, local approximation is to be developed over global approximations. The SURE filter and Joint SURE filter can be executed with the help of guidance image in denoising purpose while preserving the edges. The execution of wavelet based SURE denoising increase the efficiency of filtering. This can be applied for various real time applications, including noise reduction, enhancement and HDR compression.

Keywords— Edge Preserving Image Filtering, Local linear model, Wavelet decomposition, Denoising, Stein's Unbiased Risk Estimate (SURE), High Dynamic Range (HDR) Compression, Enhancement.

INTRODUCTION

Optical information transmitted in the form of digital images is a significant method of communication in the modern era, but the information at the receiver is often corrupted with noise. So the image needs processing before it can be used. Image denoising requires the manipulation of the image data to produce a visually arete image.

Enormous portion of digital image processing is dedicated to image restoration. This includes analysis in algorithm development and established resourceful image processing. Image restoration is the expulsion of degradation that are indulged with the image obtained at the receiver. Degradation arrives from blurring and noise due to electronic and photometric sources.

Consider the depiction of a digital image. Digital image in 2-dimension can be represented as a 2-dimensional array of data s(x,y), where (x,y) shows the pixel location.[6] The pixel value resemble the brightness of the image at location (x,y). Some of the most commonly used image types are binary, grayscale and color images. For evaluating the performance of the denoising algorithm, a high quality image is taken and some known noise is added to it. This would then be given as input to the denoising algorithm, which develops an image close to the original high quality image. The Linear operation [6] is the addition or multiplication of the noise n(x,y) to the signal s(x,y). Once the noisy image w(x,y) is obtained, it is subjected to the denoising technique to get the denoised image z(x,y).

RELATED WORKS

Recently, many novel edge-preserving smoothing filters have been proposed,consisting weighted least squares filter (WLS) [15], edge avoiding wavelets (EAW)[7], and domain transform (DT) approach [8] to approximate geodesic distance by iterating 1D-filtering operations. In particular, based on a local linear model, He et al.[9] proposed a new filtering method - guided filter that can perform effective edge preserving smoothing by the help of a guidance image. To have a better solution, He et al. introduced a regularization parameter which determines the amount of smoothing. Although edge-preserving smoothing filters are wildly used as useful tools for a variety of image editing and examining tasks, most of them are really proposed to denoise while preserving edges and geometrical structures in the original image.

Ce liu et al[3] proposed A unified framework for two tasks: automatic estimation and removal of color noise from a single image using piece wise smooth image models is estimated. Based on a simple piece wise-smooth image prior, a segmentation-based approach to automatically estimate and remove noise from color images is done. The Non Linear Filter is obtained by estimating the lower envelope of the standard deviations of image variance per segment .This automatically estimates and removes noise from color images and can be applied to computer vision applications to make them independent of noise level but it is mainly reliable for synthetic noises.

Byong Mok Oh et al [4] proposed two distinct editing methods. The first, which is a clone brushing tool, which allows the distortion-free copying of portions of an image, by using a parameterization optimization technique.. The second, which is a texture-illuminance decoupling filter, reduces the effect of illumination on uniformly textured areas. Here editing of image can be employed from different perspective, extracting and grouping of image-based objects can be done, but geometrical shapes are given more priority than real time objects.

Fredo Durand and Julie Dorsey [5] recommended Bilateral filter as a non-linear filter, where the pixel value is computed using an impact function in the intensity domain multiplied to the Gaussian in the spatial domain that decreases the weight of pixels with large intensity differences. This is based on a non iterative process in which Satisfying result is obtained in single pass. But the scheme may have Bilateral filtering may have the gradient reversal artifacts in detail decomposition and high dynamic range (HDR) compression.

Dimitri Van De Ville and Michel Kocher [10] Non-local means provides a powerful framework for denoising. SURE technique is used in the algorithm for restoration of an image corrupted by additive white Gaussian noise. The SURE concept allows assessing the MSE without knowledge of the noise-free signal. The paper depicts a satisfying result with less computational cost.

PROBLEM FORMULATION

The need for effective image restoration methods has developed with the enormous production of digital images and videos of all types, often taken in condemned situations. No matter how beneficial the cameras are, an image improvement is always sensible to improve their scope of action. The two main limitations in image accuracy are categorized as blur and noise. Blur is inherent to image acquisition systems, as digital images have fixed samples. The second main image perturbation is noise.

PROBLEM SETTING

Consider the measurement model[12] $y_i = x_i + n_i$ i = 1............N

where x_i is the underlying latent signal of interest at a position i , y_i is the noisy measured signal (pixel value), and ni is the corrupting zero-mean white Gaussian noise with σ^2. The standard simplified denoising problem is to find a reasonably good estimate $\hat{x}$ of x. To redefine the problem more incisively, the complete measurement model in vector notation is given by

$$y=x+n$$

SIGNAL TO NOISE RATIO

The higher the PSNR is, the better the performance of denoising algorithm.

$$\text{PSNR}=10\log_{10}\left(\frac{\text{MAX}(x^2)}{\text{MSE}(\hat{x})}\right)$$

Where,

$$\text{MSE}(\hat{x})=\frac{1}{N}\|x-\hat{x}\| = \frac{1}{N}\sum_{i=1}^{N}(x_i-\hat{x}_i)^2$$

Since x is the noise-free signal which does not affect the value of PSNR in any algorithm, maximizing PSNR is equivalent to minimizing MSE. However, one cannot approximate MSE without the original signal x. Thanks to Steins unbiased risk estimate

(SURE) provides a means for unbiased estimation of the true MSE, it is possible to replace MSE by SURE without any assumptions on the original signal. SURE is specified by the following expression

$$\mathrm{SURE}(\hat{x})=\frac{1}{N}\|y-\hat{x}\|+\frac{2\sigma^2}{N}\mathrm{div}_y\{\hat{x}\}-\sigma^2$$

where $\mathrm{div}_y\{\hat{x}\}$ is the divergence of the output estimate with respect to the measurements,

$$\mathrm{div}_y\{\hat{x}\}=\sum_{i=1}^{N}\frac{\delta\hat{x}i}{\delta yi}$$

METHODOLOGY

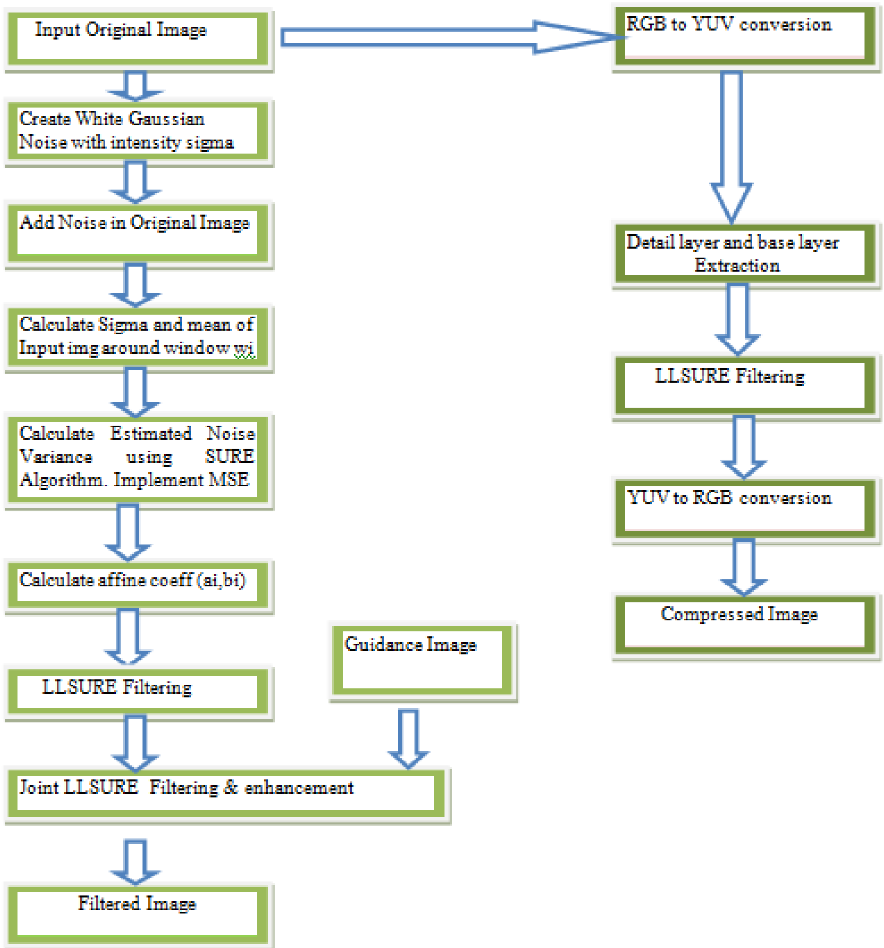

Figure 2: Block diagram of phase 1

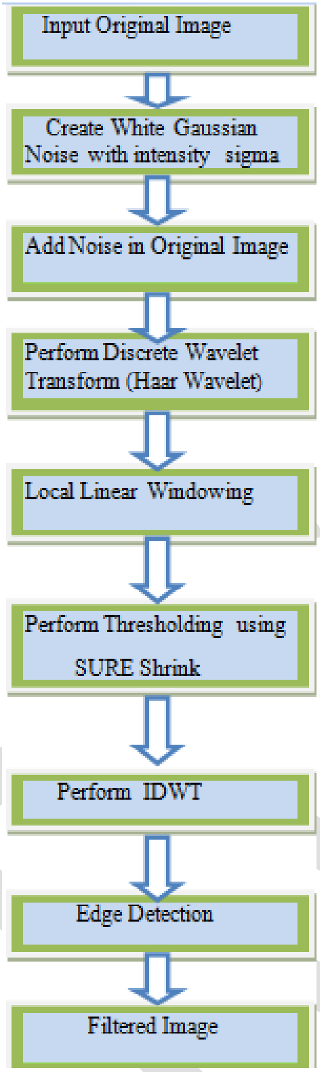

Figure 3: Block diagram of phase 2.

PHASE 1

Taking the biased estimator[12] given below,

$$\hat{x}=a*y+b$$

Where a and b are the affine coefficients, and now Considering a local window w_i, the basic SURE equation has been modified as shown below

$$\mathrm{SURE}(a_i, b_i)=\frac{1}{N_w}\|y_{wi}-(a_i y_{wi}+b_i)\|^2+2\sigma^2 a_i+\sigma^2$$

Where a_i and b_i are affine transform coefficients obtained by[12] and σ^2 is the variance of measured data. Taking partial differential equation,

$$\frac{\delta}{\delta_{b_i}}\mathrm{SURE}(a_i, b_i)=0$$

$$b_i^* = (1-a_i^*)\bar{y}_i$$

And

$$\frac{\delta}{\delta_{a_i}}\text{SURE }(a_i, b_i)=0$$

$$a_i^* = \frac{\max(\sigma_i^2 - \sigma^2, 0)}{(\sigma_i^2 + \varepsilon)}$$

Again to normalize the affine transform coefficients, consider the normalization procedure

$$\overline{a_j} = \frac{1}{w_j}\sum_{i\epsilon w_j} a_i^* \sigma_i^2, \qquad j\epsilon w_i$$

$$\overline{b_j} = \frac{1}{w_j}\sum_{i\epsilon w_j} b_i^* \sigma_i^2, \qquad j\epsilon w_i$$

Now the sure filter can be modelled as

$$\hat{x}_j^i = \overline{a_j} y_j + \overline{b_j}, \qquad j\epsilon w_i$$

For obtaining JSURE filter we consider the modified SURE equation:

$$\text{JSURE}(a_i, b_i) = \frac{1}{N_w}\|f_{wi} - (a_i y_{wi} + b_i)\|^2 + 2\sigma^2 a_i - \sigma^2$$

Where f_{wi} is filter input image patch and y_{wi} is guidance image patch. Now again by taking partial differential equation, with respect to a_i and b_i, it is obtained as[12]:

$$a_i^* = \frac{(\text{cov}(f_{wi}, y_{wi}))}{(\sigma_i^2 + \varepsilon)}$$

$$b_i^* = \bar{f}_i - a_i^* \bar{y}_i$$

Where cov is the covariance function between f_{wi} and y_{wi}.

Now the sure filter can be modelled as

$$\hat{x}_j^i = a_j^* y_j + b_j^*, \qquad j\epsilon w_i$$

The key idea of a fine aggregation procedure is how to choose the weight for getting the best estimate. The simplest method of aggregating such multiple estimates is to average them using equal weight.

HDR COMPRESSION

HDRI is an image that has a greater dynamic range that can be shown on a display device or recorded with a camera with just a single exposure. Here, RGB image is converted to YUV. Then, Separation of base layer and detail layer is done [12]; preceding the application of LLSURE Filter.And finally YUV is converted back to RGB image.

PHASE 2

HAAR WAVELET

Wavelets are a set of non-linear bases. When approximating a function regarding wavelets, the wavelet basis functions are selected with respect to the function being approximated. The haar transform is the simplest kind of wavelet. The corresponding algorithm [13] transforms a 2-element vector $[x(1), x(2)]^T$ into $[y(1), y(2)]^T$ by relation:

$$\begin{bmatrix} (x(1) \\ x(2) \end{bmatrix} = T\begin{bmatrix} y(1) \\ y(2) \end{bmatrix}$$

Where, $T=\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\ 1 & -1\end{bmatrix}$ is an orthonormal matrix; which implies, $T^{-1} = T^{T}$. and it is possible [14] to recover x from y by relation:

$$\begin{bmatrix}(x(1)\\ x(2)\end{bmatrix}=T^{T}\begin{bmatrix}y(1)\\ y(2)\end{bmatrix}$$

In 2-dimensions x and y become 2 × 2 matrices. We can transform the columns of x first, by pre-multiplying by T, and then the rows of the result by post-multiplying by T^{T} to find y $=T*T^{T}$. And then, $x=T^{T}y\,T$.

By doing so, we get image as shown below:

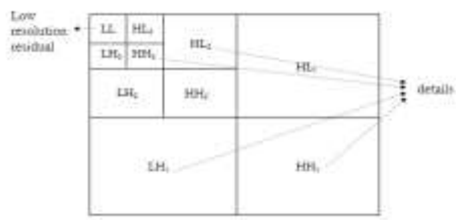

Figure 4: wavelet decomposition

THRESHOLD ESTIMATION

A dispute in the wavelet shrinkage process is to find a sufficient threshold value. A small threshold will bear the majority of the coefficients related with the noisy signal, then resulting a signal that may still be noisy. Moreover, a large threshold will shrink most coefficients, which leads to a smoothing of the signal that may subdue the important features of the image.

A separate threshold is estimated for each sub band based on Stein's unbiased risk estimator (SURE) known as SureShrink.

$$\lambda_s = \text{argmin}_{t\geq 0}\text{SURE}(t,G_s)$$

Where, $$\text{SURE}(t,G_s) = NS - 2[1 : NS]+\sum_{x,y=1}^{N_s}\left[\min G_{x,y}, t\right]^2$$

G_s is the detail coefficients from subband S and NS is the number of coefficients $G_{x,y}$ in $\{G_s\}$. As suggested by Donoho and Johnstone [15], when the coefficients are not very sparse, then Sure Shrink is applied, if not, universal threshold is applied. Universal threshold proposed by Donoho and Johnstone [15], defined as

$$\lambda v=\hat{\sigma}\text{noise}\sqrt{2\log L}$$

Where$(\hat{\sigma}\text{noise})^2$ is estimated noise deviation and L is the total number of pixels (M*N).

SIMULATION

The simulation is done on MATLAB. The test image include the image of Lena and a HDR image for compression. PSNR for the first phase(Lena) is obtained as 17 dB and for the second phase is 25.119dB. The Figure 5 shows the noisy image. Figure6 and Figure & shows output of phase 1 and phase 2 respectively. The compression for HDR image is also shown in Figure 9.

Figure 5: Noisy image with sigma 22

Figure 6: output of phase 1

Figure 7: output of phase 2

Figure 8: HDR input image

Figure 9: HDR compressed image.

ACKNOWLEDGMENT

I am grateful to the Lord almighty, merciful and passionate, for providing me this opportunity and granting me the capability to proceed successfully. I am thankful to my parents, professors, friends and well-wishers for the valuable advice and support.

CONCLUSION

The most important task in image processing is denoising with preserving edges. A better quality image filtering method is present with several desirable features which include a flexible and versatile methodology. The geometrical structures are preserved while removing the noise and can be applied in image processing and computer vision applications.

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