



**AN EFFICIENT IMAGE DENOISING METHOD
BY COMBINING WEIGHTED LEAST SQUARE
AND GUIDED FILTERS**



PROJECT REPORT

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BONAFIDE CERTIFICATE

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ABSTRACT

Reducing noise has always been one of the important problem of image analysis and processing. While reducing noise, it is important to preserve the edges because it is of critical importance to the visual appearance of the image. In this project, image denoising is done with the help of edge preserving filters such as Bilateral, Guided filters and Hybrid Filter(Guided and Weighted Least Square filters). Bilateral filter is a non-linear combination of nearby image values and it is non-iterative, local and simple. Bilateral filter has certain disadvantages like staircase effect and gradient reversal which is overcome by guided filter. Guided filter is a linear model which generates the filtering output by considering the content of a guidance image, which can be the input image itself or another different image. Guided filter has better behaviour near edges than bilateral filter. Guided Filtering output suffers from halo effect which is overcome by WLS filter. In this paper, Guided filter is combined with WLS filter overcoming the disadvantages of both bilateral and guided filters producing better results quantitatively and qualitatively.

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LIST OF ABBREVIATIONS

RGB	Red Green Blue
CCD	Charge Coupled Device
HSV	Hue,Saturation, Value
CWM	Central Weighted Median
TV	Total Variation
NLM	Non Local Means
SURE	Stein's Unbiased Risk Estimate
MSE	Mean Square Error
SSIM	Structural Similarity Index
PSNR	Peak Signal to Noise Ratio

CHAPTER 1

INTRODUCTION

1.1 Definition of a Digital Image:

A digital image (also called a discrete image) is obtained from an analogue image by sampling and quantization. This process depends on the acquisition device and depends, for instance, on CCDs for digital cameras. Basically, the idea is to superimpose a regular grid on an analogue image and to assign a digital number to each square of the grid, for example the average brightness in that square. Each square is called a pixel, for picture element, and its value is the gray-level or brightness.

1.2 Characteristics of image:

1. The space domain S , which is the set of possible positions in an image. This is related to the resolution, i.e., the number of rows and columns in the image. Consumer-grade cameras now give images with several megapixels (i.e. millions of pixels), typically between 5 and 10, professional cameras provides up to 16 megapixels, and some prototypes reach several hundreds of megapixels or even a few gigapixels.
2. The range domain R , which is the set of possible pixel values. The number of bits used to represent the pixel value may vary. Common pixel representations are unsigned bytes (0 to 255) and floating point. To describe a pixel, one may also need several channels (or bands): for example, a vector field has two components, a color image is described with three channels, red, green and blue (or any other color space such as hue, saturation, value, namely HSV).

1.3 Image denoising:

One of the fundamental challenges in the field of image processing and computer vision is image denoising, where the underlying goal is to estimate the original image by suppressing noise from a noise-contaminated version of the image. Image noise may be caused by different intrinsic (i.e., sensor) and extrinsic (i.e., environment) conditions which are often not possible to avoid in practical situations. Therefore, image denoising plays an important role in a wide range of applications such as image restoration, visual

tracking, image registration, image segmentation, and image classification, where obtaining the original image content is crucial for strong performance. While many algorithms have been proposed for the purpose of image denoising, the problem of image noise suppression remains an open challenge, especially in situations where the images are acquired under poor conditions where the noise level is very high. So the challenge of good image denoising model is that it has to remove noise while preserving edges.

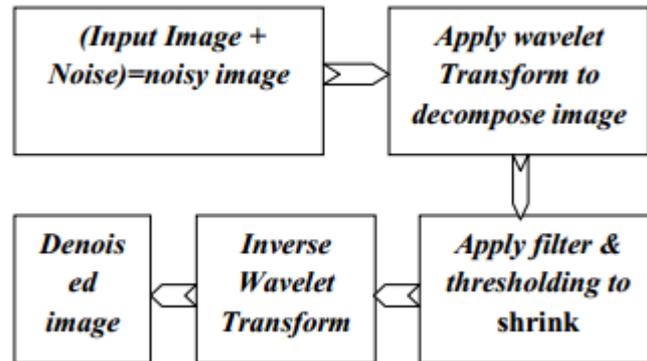


Fig 1.1 Basic model of image denoising

1.4 General classification of image denoising techniques :

There are basic two approaches of the image denoising: spatial domain filtering and transform domain filtering.

1.4.1 Spatial domain filtering

A traditional way to remove noise from image data is to employ spatial filters. Spatial domain filtering methods take original noisy image into consideration and apply filtering process on it. Spatial filters are direct and high speed processing tools of images.

1.4.1.1 Linear filters

Linear filters like mean filter, Wiener filter too tend to blur sharp edges, destroy lines and other fine image details, and perform poorly in the presence of signal-dependent noise.

Mean filtering is a simple, intuitive and easy to implement method of reducing noise in images. The idea of mean filtering is simply to replace each pixel value in an image with the mean ('average') value of its neighbours, including itself. The Wiener filtering method requires the information about the spectra of the noise and the original signal and it works well only if the underlying signal is smooth.

1.4.1.2 Non-linear filters

With non-linear filters, the noise is removed without any attempts to explicitly identify it. To resolve the issues raised with linear filters, a variety of non-linear filters such as median, weighted median, rank conditioned rank selection, and relaxed median have been developed.

1.4.2 Transform domain filtering

In contrast with spatial domain filtering methods, transform domain filtering methods first obtain some transform of given noisy image and then apply denoising procedure on transformed image. The transform domain filtering methods were subdivided according to the choice of the basis transform functions which may be data adaptive or non-data adaptive.

1.4.2.1 Data adaptive transform

The transform domain filtering methods that made choice of data adaptive transform functions include a popular example of Independent Component Analysis (ICA) method. This method is successfully implemented for denoising of non-Gaussian data. This method assumes that signal should be non-Gaussian. This assumption helps to denoising images with non-Gaussian as well as Gaussian distribution. The main drawback with ICA method is its computational cost because it uses a sliding window and requires sample of noise free data or at least two image frames of the same scene. But in some applications, it might be difficult to obtain the noise free training data.

1.4.2.2 Non-data adaptive transform

The transform domain filtering methods that made choice of non-data adaptive transform functions were further subdivided into two domains namely spatial-frequency domain and wavelet domain.

Spatial-frequency domain:

Filtering methods in spatial-frequency domain refer use of low pass filtering by designing a frequency domain filter that passes all the frequencies lower than and attenuates all the frequencies greater than a cut-off frequency. Before application of filtering method, domain of given noisy image is changed from spatial to frequency using Fast Fourier Transform (FFT). These methods are time consuming and depend on the cut-off frequency and the filter function behaviour. Furthermore, they may produce artificial frequencies in the processed image.

Wavelet domain:

For denoising in wavelet domain, various algorithms based on wavelet transform have been developed. The focus was shifted from the spatial and Fourier domain to the wavelet transform domain. It has been proved that the use of wavelets successfully removes noise while preserving the signal characteristics, regardless of its frequency content

Similar to spatial domain filtering, filtering operations in the wavelet domain can also be subdivided into linear and non-linear methods. Linear wavelet domain methods include the most popular example of Wiener filters while non-linear wavelet domain methods include coefficient thresholding based methods

1.5 Project goal:

The project aim is to calculate the intensity and apply hybrid Filter(WLS and Guided Filter) to avoid halo and gradient reversal artifacts.

1.6 Software used

1. ModelSim 6.4a
2. Matlab 2012b
3. Quartus II 6.4a

1.7 Organization of the report

Chapter 2 discusses on literature survey on edge preserving filters

Chapter 3 discusses on Noise

Chapter 4 discusses on Filter description

Chapter 5 describes the Work flow

Chapter 6 gives the simulation results

Chapter 7 gives the Conclusion and Future Work

CHAPTER 2

LITERATURE SURVEY

Edges are of critical importance to the visual appearance of images. So, it is desirable to preserve important features, such as edges, corners and other sharp structures, during the denoising process. This chapter presents the literature survey of some of the edge preserving filters in image processing.

2.1 Median filter:

The median filter is also a sliding-window spatial filter, but it replaces the center value in the window with the median of all the pixel values in the window.

Vijayakumar.V.R et.al.[1], presented a paper on median filter for removing salt and pepper noise and random valued impulse noise with edge and detail preservation. The method proposed by them first detects the impulse pixel based on threshold values and then the corrupted pixels are replaced by the median value of the uncorrupted pixels in the filtering window.

Bhateja.V et.al. [2] presented a non-iterative adaptive median filter for denoising images contaminated with impulse noise. This scheme operates in two steps. Firstly, the pixels are segregated as 'noisy' and 'noise-free' so that the subsequent processing can be carried out only for the noisy pixels only in the next step. Secondly, the identified noisy pixels are replaced by the median value or by its neighbouring pixel value. Further, the 'non-iterative' feature projects that there is no need of recursive filtering to reduce the residual noise content. This method is tested on images with different characteristics and is found to produce better results in terms of the qualitative and quantitative measures of the image in comparison to other filtering approaches.

Chin-Chen Chang et al[13] presented a paper based on standard median(SM) filter. This method uses a threshold and the standard median to detect noise and change the original pixel value to a newer that is closer to or the same as the standard median. They also incorporated the center weighted median (CWM) filter.

2.2 Total variation based filtering:

It is based on the principle that signals with excessive and possibly spurious detail have high total variation, that is, the integral of the absolute gradient of the signal is high. According to this principle, reducing the total variation of the signal subject to it being a close match to the original signal, removes unwanted detail while preserving important details such as edges.

Rudin et al[3] presented a non-linear, constrained optimization type of numerical algorithm for image denoising. The total variation (TV) of the image is minimized subject to constraints involving the statistics of the noise. The constraints were imposed using Lagrange multiplier. The proposed algorithm was simple and relatively fast. It provided good edge-preservation.

Goto.T et al [4] presented a paper in total variation filter where an image is decomposed to a skeleton component, which consists of smooth luminance and edges, and a texture component, which consists of small signals and noise. The Sobel filter is used for edge detection from the skeleton component, and the texture component corresponding to around the edges are filtered by using the Median filter. As a result, the blocky noise and mosquito noise in the reconstructed images are reduced, and fine images are obtained.

2.3 Anisotropic diffusion:

Anisotropic Diffusion is a technique aiming at reducing image noise without removing significant parts of the image content, typically edges, lines or other details that are important for the interpretation of the image

Perona et al[5] provided edge detection using non-linear anisotropic diffusion smoothing method. In anisotropic diffusion, local image variation is measured at every point, and pixel values are averaged from neighbourhoods whose size and shape depend on local variation

Weickert et al [6] suggested some efficient and reliable schemes for non-linear diffusion filtering. Diffusion methods used partial differential equations and were implemented as iterative process which is usually slow and may raise issues of stability and efficiency.

2.4 Non local means:

Non-local means filtering takes a mean of all pixels in the image, weighted by how similar these pixels are to the target pixel. This results in much greater post-filtering clarity, and less loss of detail in the image compared with local mean algorithms.

De Ville Kocher et al [7] proposed to use Stein's unbiased risk estimate(SURE) to monitor the mean square error (MSE) of the NLM algorithm for restoration of an image corrupted by additive white Gaussian noise. The SURE principle allows assessing the MSE without knowledge of the noise-free signal. They derive an explicit analytical expression for SURE in the setting of NLM that can be incorporated in the implementation at low computational cost.

Ertas.M. et al [8] presented a paper on non-local means to suppress the Gaussian noise and preserve fine details in the image. They combined total variation minimization with NLM filtering to increase the noise reduction. Visual and numerical results show that an important improvement in image denoising has been achieved in the sense of Structure Similarity (SSIM) and RMSE.

2.5 Bilateral filter:

A bilateral filter is a non-linear, edge-preserving and noise-reducing smoothing filter for images. The intensity value at each pixel in an image is replaced by a weighted average of intensity values from nearby pixels. This weight can be based on a Gaussian distribution. The weights depend not only on Euclidean distance of pixels, but also on the radiometric differences. This preserves sharp edges by systematically looping through each pixel and adjusting weights to the adjacent pixels accordingly.

Michael Elad[9] presented a paper related to Tomashi et al[10] non-iterative bilateral filter. The bilateral filter was proposed as an intuitive tool without theoretical connection to the classical approaches here, they proposed a bridge where bilateral filter emerges from the Bayesian approach, as a single iteration of some well-known iterative algorithm.

Gang Dong et al[11] presented a paper to study the convergence properties of the bilateral filter algorithm. The understanding is established that bilateral filter is an optimization procedure. We demonstrate that the bilateral filter is equivalent to minimizing a robust cost criterion using iterative reweighting, which is a good approximation to the very fast but unstable Newton's method. Further, the results of the analysis allow us to derive an improved hybrid smoothing scheme with concerns of computational efficiency and edge preservation.

2.6 Guided Filter:

The guided filter computes the filtering output by considering the content of a guidance image, which can be the input image itself or another different image. The guided

filter can be used as an edge-preserving smoothing operator like the popular bilateral filter [10] but it has better behaviours near edges.

Kaiming He et al[12] presented a paper on guided filter indicating that it is a more generic concept beyond smoothing. It can transfer the structures of the guidance image to the filtering output, enabling new filtering applications like dehazing and guided feathering. Moreover, the guided filter naturally has a fast and non approximate linear time algorithm, regardless of the kernel size and the intensity range. Currently, it is one of the fastest edge-preserving filters.

CHAPTER 3

NOISE

Noise is a random variation of image Intensity and visible as grains 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. It may produce at the time of capturing or image transmission. Noise means, the pixels in the image show different intensity values instead of true pixel values. Noise removal algorithm is the process of removing or reducing the noise from the image. The noise removal algorithms reduce or remove the visibility of noise by smoothing the entire image leaving areas near contrast boundaries. But these methods can obscure fine, low contrast details. The common types of noise that arises in the image are a) Impulse noise, b) Additive noise, c) Multiplicative noise. Different noises have their own characteristics which make them distinguishable from others.

3.1 Sources of noise in an image

Noise is introduced in the image at the time of image acquisition or transmission. Different factors may be responsible for introduction of noise in the image. The number of pixels corrupted in the image will decide the quantification of the noise. The principal sources of noise in the digital image are:

- a) The imaging sensor may be affected by environmental conditions during image acquisition.
- b) Insufficient Light levels and sensor temperature may introduce the noise in the image.
- c) Interference in the transmission channel may also corrupt the image.
- d) If dust particles are present on the scanner screen, they can also introduce noise in the image

3.2 TYPES OF NOISE:

Noise is the undesirable effects produced in the image. During image acquisition or transmission, several factors are responsible for introducing noise in the image. Depending on the type of disturbance, the noise can affect the image to different extent. Image noise can be classified as Impulse noise (Salt-and-pepper noise), Amplifier noise (Gaussian noise), Shot

noise, Quantization noise (uniform noise), Film grain, on-isotropic noise, Multiplicative noise (Speckle noise) and Periodic noise.

3.2.1 Impulse Noise(Salt and Pepper Noise):

The term impulse noise is also used for this type of noise. Other terms are spike noise, random noise or independent noise. Black and white dots appear in the image as a result of this noise and hence salt and pepper noise. This noise arises in the image because of sharp and sudden changes of image signal. Dust particles in the image acquisition source or over heated faulty components can cause this type of noise

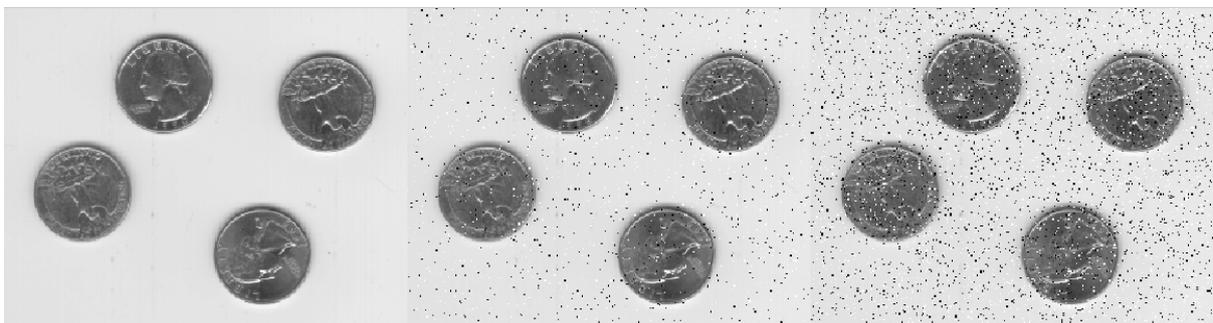


Fig 3.1 : Input image, Input image with salt and pepper noise having noise density 0.02 and 0.06

3.2.2 Gaussian Noise(Amplifier Noise):

This noise model is additive in nature and follow Gaussian distribution. Meaning that each pixel in the noisy image is the sum of the true pixel value and a random, Gaussian distributed noise value. The noise is independent of intensity of pixel value at each point.

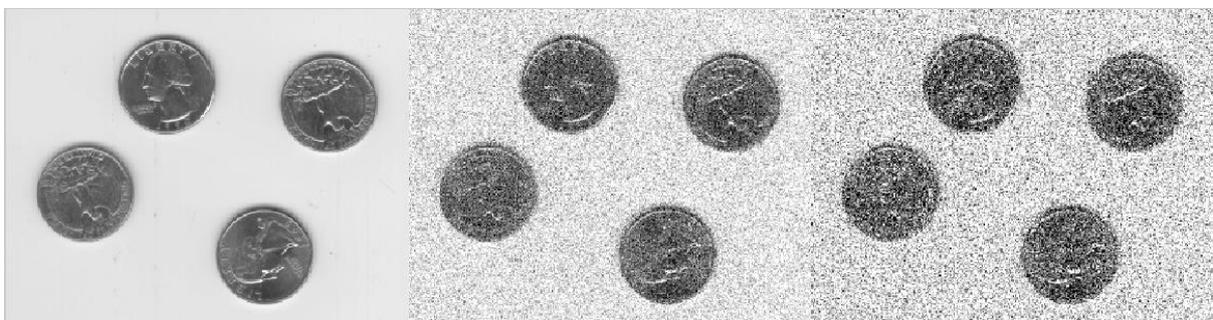


Fig 3.2 : Input image, Input image with Gaussian noise having noise density 0.02 and 0.06

The PDF of Gaussian random variable is given by

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Where $P(x)$ is the Gaussian distribution noise in image,

μ and σ is the mean and standard deviation respectively.

3.2.3 Poisson Noise:

Poisson or shot photon noise is the noise that can cause, when number of photons sensed by the sensor is not sufficient to provide detectable statistical information. This noise has root mean square value proportional to square root intensity of the image. Different pixels are suffered by independent noise values. At practical grounds the photon noise and other sensor based noise corrupt the signal at different proportions.



Fig 3.3 : Input image, Input image with Poisson noise

3.2.4 Speckle Noise:

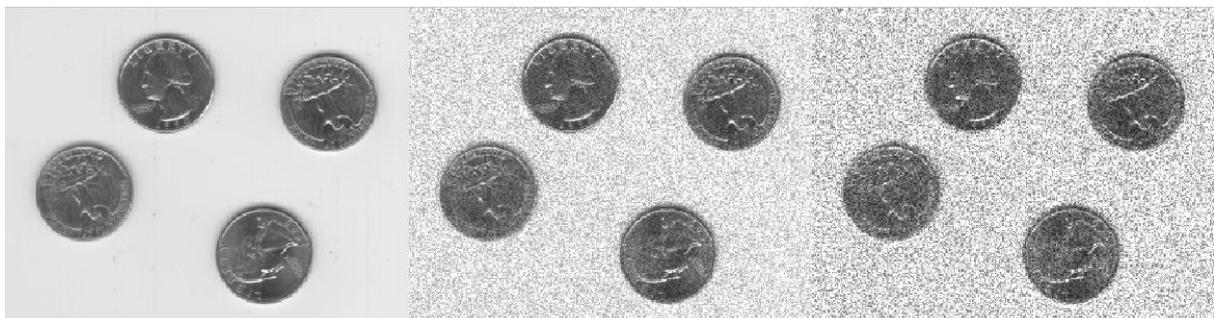


Fig 3.4 : Input image, Input image with speckle noise with mean 0 ,variance 0.02 and 0.06

This noise can be modelled by random value multiplications with pixel values of the image and can be expressed as

$$J = I + n * I$$

Where, J is the speckle noise distribution image, I is the input image and n is the uniform noise image by mean 0 and variance v. This noise deteriorates the quality of active radar and Synthetic aperture radar (SAR) images. This noise is originated because of coherent processing of back scattered signals from multiple distributed points. In conventional radar system this type of noise is noticed when the returned signal from the object having size less than or equal to a single image processing unit, shows sudden fluctuations. Mean filters are good for Gaussian noise and uniform noise.

CHAPTER 4

FILTER DESCRIPTION

Digital images can be corrupted by noise during the process of acquisition and transmission, degrading their quality. Image denoising is one of the fundamental challenges in the field of image processing and computer vision, where the underlying goal is to estimate the original image by removing noise from a noisy version of the image. A major challenge is to remove noise as much as possible without eliminating the most representative characteristics of the image, such as edges, corners and other sharp structures.

Ideally denoising is all about filtering noise from the degraded image while keeping other details unchanged. Indeed, filtering is the most fundamental operation of image processing and computer vision and it is used extensively in a wide range of applications, including image smoothing and sharpening, noise removal, resolution enhancement and reduction, feature extraction and edge detection. In the broadest sense of the term “filtering”, the value of the filtered image at a given location is a function of the values of the input image in a small neighbourhood of the same location.

In this chapter image denoising methods like Bilateral, Guided and Weighted Least Square filters are discussed. These three filters reduce noise while preserving edges.

4.1 Bilateral filter:

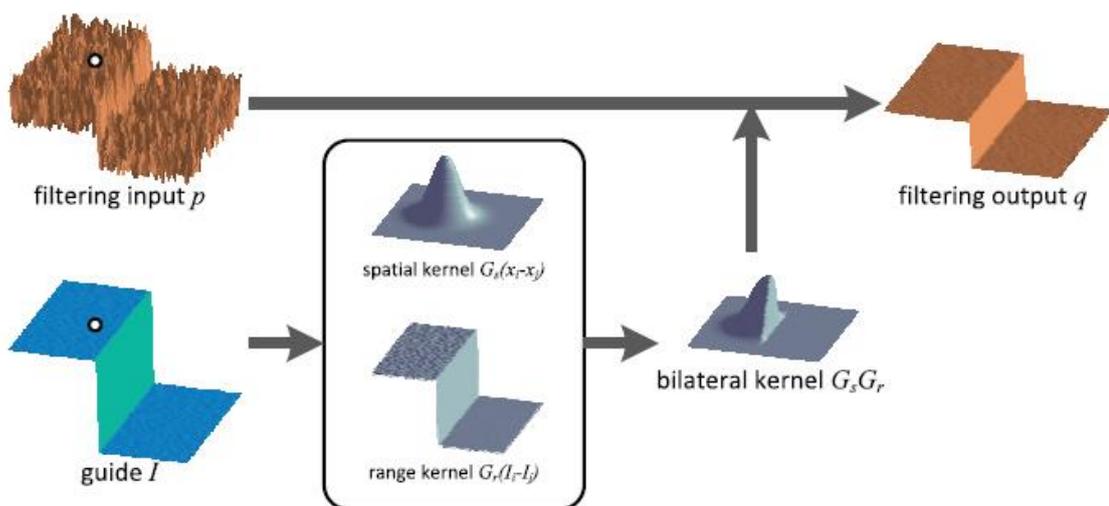


Fig 4.1 Illustration of bilateral filter

Bilateral filtering has gained great popularity in image processing due to its capability of reducing noise while preserving the structural information of an image. The bilateral filter consists of two components. The detail-preserving property of the filter is mainly caused by the nonlinear filter component also called photometric filter. It selects the pixels of similar intensity which are averaged by the linear component afterward. Very often, the linear component is formulated as a low-pass filter. The amount of noise reduction via selective averaging and the amount of the blurring via low-pass filtering are both adjusted by two parameters.

The bilateral filter embodies the idea of a combination of domain and range filtering. The domain filter averages the nearby pixel values and acts thereby as a low-pass filter. The range filter stands for the nonlinear component and plays an important part in edge preserving. This component allows averaging of similar pixel values only, regardless of their position in the filter window. If the value of a pixel in the filter window diverges from the value of the pixel being filtered by a certain amount, the pixel is skipped.

Taking Gaussian noise into account, the shift-variant filtering operation of the bilateral filter is given by

$$\bar{\phi}(\bar{\mathbf{m}}_0) = \frac{1}{k(\mathbf{m}_0)} \sum_{\mathbf{m} \in F} \phi(\mathbf{m}) \cdot s(\phi(\mathbf{m}_0), \phi(\mathbf{m})) \cdot c(\mathbf{m}_0, \mathbf{m}). \quad (1)$$

The term $\mathbf{m} = (m, n)$ denotes the pixel coordinates in the image to be filtered and $\mathbf{m}_0 = (m_0, n_0)$ and $\bar{\mathbf{m}}_0 = (\bar{m}_0, \bar{n}_0)$ represent the coordinates of the centered pixel in the noisy and in the filtered images, respectively. With these notations, $\phi(\bar{\mathbf{m}}_0)$ means the gray value of the pixel being filtered, and $\phi(\mathbf{m})$ identifies the gray value of the spatially neighboring pixels to $\phi(\mathbf{m}_0)$ in the filter window F .

The following expressions (2) and (3) describe the photometric and the geometric components $s(\phi(\mathbf{m}_0), \phi(\mathbf{m}))$ and $c(\mathbf{m}_0, \mathbf{m})$, respectively:

$$s(\phi(\mathbf{m}_0), \phi(\mathbf{m})) = \exp\left(-\frac{1}{2} \left(\frac{\|\phi(\mathbf{m}_0) - \phi(\mathbf{m})\|}{\sigma_{\text{ph}}}\right)^2\right) \quad (2)$$

$$c(\mathbf{m}_0, \mathbf{m}) = \exp\left(-\frac{1}{2} \left(\frac{\|\mathbf{m}_0 - \mathbf{m}\|}{\sigma_c}\right)^2\right) \quad (3)$$

Where parameters σ_{ph} and σ_c regulate the width of the Gaussian curve assigned to $s(\phi(m_0), \phi(m))$ and $c(m_0, m)$ respectively.

The photometric component compares the gray value of the centered pixel with the gray values of the spatial neighbourhood and computes the corresponding weight coefficients depending on the factor σ_{ph} . The more the absolute difference of the gray values exceeds σ_{ph} , the lower is the corresponding filter coefficient and vice versa. The domain filter $c(m_0, m)$ acts as a standard low-pass filter, the weights of which are reciprocally proportional to the spatial distance of the centered pixel to the pixels in the neighborhood.

Normalization with

$$k(\mathbf{m}_0) = \sum_{\mathbf{m} \in F} s(\phi(\mathbf{m}_0), \phi(\mathbf{m})) \cdot c(\mathbf{m}_0, \mathbf{m}) \quad (4)$$

guarantees that the range of the filtered images does not change significantly due to the filtering. Owing to the fact that the coefficients of the photometric component cannot be computed in advance, the division by the normalization factor cannot be avoided by means of prescaling of the filter coefficients.

4.1.1 Merits of bilateral filter:

1. In contrast with filters that operate on the three bands of a color image separately, a bilateral filter can smooth colors and preserve edges in a way that is tuned to human perception
2. Bilateral filtering produces no phantom colors along edges in color images, and reduces phantom colors where they appear in the original image

4.1.2 Limitations of bilateral filter:

1. Staircase effect - intensity plateaus that lead to images appearing like cartoons
2. Gradient reversal - introduction of false edges in the image

4.1.3 Applications of bilateral filter:

1. Denoising : This is of course the primary goal of bilateral filter, and it has been used in several applications such as medical images, movie restoration, etc. Some fields of applications are described. An extension of the bilateral filter will be presented: the cross bilateral filter.
2. Contrast Management - Bilateral filtering has been particularly successful as a tool for contrast management tasks such as detail enhancement or reduction. The bilateral

filter is used to separate an image into a large-scale component and a small-scale component by subtracting filtered results.

3. Data Fusion - These applications use bilateral filtering to decompose several source images into components and then recombine them as a single output image that inherits selected
4. Texture and Illumination Separation, Tone Mapping, Retinex, and Tone Management: Based on a large-scale / small-scale decomposition of images, these applications edit texture and manipulate the tonal distribution of an image to match the capacities of a given display or achieve photographic stylization.
5. Three-dimensional Fairing: This is the counterpart of image denoising for three-dimensional meshes and point clouds. Noise is removed from these data sets.

4.2 Guided filter:

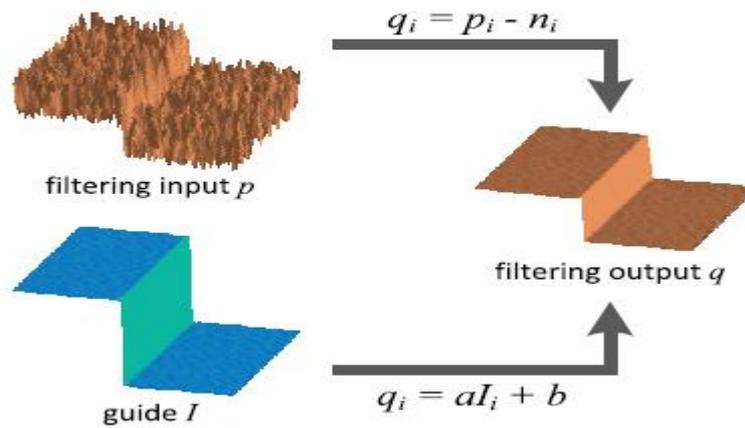


Fig 4.2 Illustration of guided filter

We first define a general linear translation-variant filtering process, which involves a guidance image I , an filtering input image p , and an output image q . Both I and p are given beforehand according to the application, and they can be identical. The filtering output at a pixel i is expressed as a weighted average:

$$q_i = \sum_j W_{ij}(I)p_j, \quad (5)$$

where i and j are pixel indexes. The filter kernel W_{ij} is a function of the guidance image I and independent of p . This filter is linear with respect to p .

Now we define the guided filter. The key assumption of the guided filter is a local linear model between the guidance I and the filtering output q . We assume that q is a linear transform of I in a window centered at the pixel k :

$$q_i = a_k I_i + b_k, \forall i \in \omega_k, \quad (6)$$

Where (a_k, b_k) are some linear coefficients. To determine the linear coefficients (a_k, b_k) we need constraints from the filtering input p . We model the output q as the input p subtracting some unwanted components n like noise/textures:

$$q_i = p_i - n_i. \quad (7)$$

So after computing (a_k, b_k) for all windows ω_k in the image, we compute the filtering output by

$$q_i = \frac{1}{|\omega|} \sum_{k|i \in \omega_k} (a_k I_i + b_k). \quad (8)$$

4.2.1 Algorithm:

Input: filtering input image p , guidance image I , radius r , regularization ε

Output: filtering output q .

1. $\text{mean}_I = f_{\text{mean}}(I)$
 $\text{mean}_p = f_{\text{mean}}(p)$
 $\text{corr}_I = f_{\text{mean}}(I * I)$
 $\text{corr}_{Ip} = f_{\text{mean}}(I * p)$
 2. $\text{var}_I = \text{corr}_I - \text{mean}_I * \text{mean}_I$
 $\text{corr}_{Ip} = \text{corr}_{Ip} - \text{mean}_I * \text{mean}_p$
 3. $a = \text{cov}_{Ip} ./ (\text{var}_I + \varepsilon)$
 $b = \text{mean}_p - a * \text{mean}_I$
 4. $\text{mean}_a = f_{\text{mean}}(a)$
 $\text{mean}_b = f_{\text{mean}}(b)$
 5. $q = \text{mean}_a * I + \text{mean}_b$
- f_{mean} is the mean filter

4.2.2 Merits of guided filter:

1. This filter has the edge-reserving smoothing property like the bilateral filter, but does not suffer from the gradient reversal artifacts.
2. The guided filter has an $O(N)$ time (in the number of pixels) exact algorithm for both gray-scale and color images.
3. The guided filter performs very well in terms of both quality and efficiency

4.2.3 Applications of guided filter:

1. Image smoothing/enhancement
2. HDR compression-The HDR compression is done in a similar way, but compressing the base layer instead of magnifying the detail layer
3. Flash/no-flash imaging-denoise a no-flash image under the guidance of its flash version.
4. Matting/feathering-combined with the global sampling method, the guided filter is the best performing filtering based matting method in the alphasammatting benchmark
5. Dehazing
6. Joint upsampling- Joint upsampling is to upsample an image under the guidance of another image.

4.3 Weighted Least Square Filter:

WLS Filter is also an edge preserving filter which doesn't suffer from halo artifacts like Guided Filter. Given an input image g , we seek a new image u , which, on the one hand, is as close as possible to g , and, at the same time, is as smooth as possible everywhere, except across significant gradients in g . Formally, this may be expressed as seeking the minimum of

$$\sum_{i=1}^M \sum_{j=1}^N (u(i,j) - g(i,j))^2 + \lambda (a_{x,g}(i,j) \left(\frac{\partial u}{\partial x}\right)_{i,j}^2 + a_{y,g}(i,j) \left(\frac{\partial u}{\partial y}\right)_{i,j}^2) \quad (9)$$

where the first term in the summation is the data term, whose objective is to minimize the distance between u and g . The second term in the summation is called as the regularization term, whose objective is to achieve smoothness by minimizing the partial derivative of u . λ provides a balance between the two terms. Increasing the value of λ leads to progressively smoother images. $a_{x,g}(i,j)$ and $a_{y,g}(i,j)$ are the smoothness weights along x and y and is dependent on g .

It is given as

$$\mathbf{a}_{x,g}(\mathbf{i}, \mathbf{j}) = \left(\left| \frac{\partial l}{\partial x} \right|_{\mathbf{i}, \mathbf{j}}^{\alpha} + \varepsilon \right)^{-1}$$
$$\mathbf{a}_{y,g}(\mathbf{i}, \mathbf{j}) = \left(\left| \frac{\partial l}{\partial y} \right|_{\mathbf{i}, \mathbf{j}}^{\alpha} + \varepsilon \right)^{-1}$$

Where l is the log-luminance channel of the input image g , α decides the sensitivity to the gradients of g , and ε is a constant whose value is 0.0001 and comes of purpose where ever g is constant.

WLS Filter is used in variety of applications, including tone mapping, contrast manipulation, and image abstraction, and it is robust and versatile.

CHAPTER 5

WORK FLOW

Colour image \longrightarrow Gray colour image \longrightarrow hex file(Data_in)

The input(colour)image is converted to gray colour image, then the image is converted to hex file. The hex file from MATLAB is given as input to MODELSIM. In MODELSIM, salt and pepper noise is added to the gray colour image and noise file is generated. The design concept for bilateral filter is divided into three functional blocks like below.

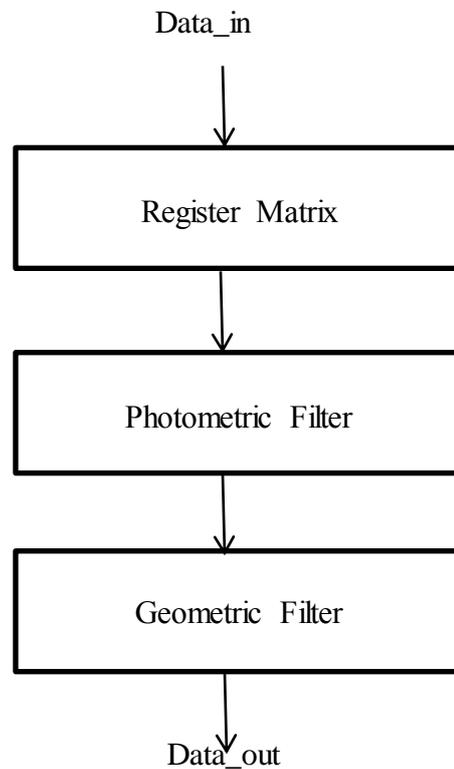


Fig 5.1 Functional units of bilateral filter

The Data_in are read line by line and arranged for further processing in register matrix. The second unit is the photometric filter which weights the input data according to the intensity of the processed pixels. This component is also referred to as range filter which is a non-linear filter. The filtering is completed by the geometric filter which consists of array multiplier and adder. The filtered data from geometric filter is given as data_out. The Data_out is opened in MATLAB to view the bilateral filter output image

In guided filtering, an additional guidance image is present which preserves edges better than bilateral filter.

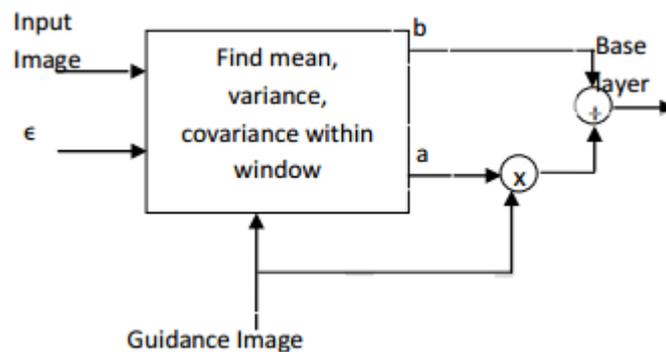


Fig 5.2 Block diagram of Guided image filter

Fig 5.2 represents the block diagram of the guided image filter where a and b are the filter coefficients computed by the input image and guidance image. The output is obtained as hex file in MODELSIM and therefore the hexfile is opened in MATLAB to view the filtering output of guided filter.

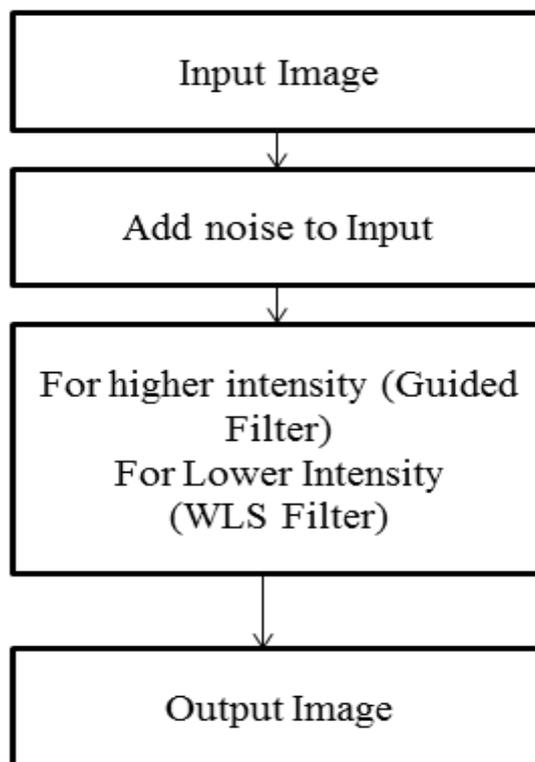


Fig 5.3 Block diagram of Hybrid Filter

Fig 5.3 represents the block diagram of Guided Filter. In Guided Filter, halo effect occurs in low intensity regions, in order to avoid that this filter is combined with Weighted Least Square Filter which overcomes this disadvantage.

The procedure is as follows

- 1) Add Noise to the input.
- 2) Calculate the intensity level of the image
- 3) If the Intensity is less than midvalue of 255 (maximum intensity), WLS Filter is applied else Guided Filter is applied to the image.

By combining these two filters, edges are preserved without suffering from halo and gradient reversal artifacts.

CHAPTER 6

SIMULATION RESULTS

6.1 INTRODUCTION:

The results of Bilateral, Guided and Hybrid Guided Filter on various images are presented in this chapter. The performance measure that has been used to analyze results are Peak Signal to Noise ratio (PSNR) and Structural Similarity index (MSSIM).

The algorithm of all the three filters are simulated in MODELSIM and the resultant images are viewed in MATLAB. Here, Area and Power are also calculated with the help of Quartus II.

6.2 PERFORMANCE METRICS:

The results are analysed using different quality metrics which are detailed below:

- **Mean Square Error:**

Mean Square Error is the average squared difference between a reference image and reconstructed image. For a m x n reference image I and reconstructed image K, the MSE is given by:

$$MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [I(i, j) - K(i, j)]^2$$

- **Peak Signal to Noise Ratio:**

Peak Signal to Noise Ratio is the ratio between the reference image and the reconstructed image, given in decibels. The higher the PSNR value, the closer the reconstructed image is to the reference image.

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

where MAXI is the maximum possible pixel value of the image. MAXI=255 for 8-bit images.

- **Structural Similarity Index:**

The structural similarity (SSIM) index is a method for measuring the similarity between two images. It is calculated on various windows of an image. The measure between two windows x and y of common size N×N is:

$$SSIM(x, y) = \frac{2(\mu_x \mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

Where μ_x and μ_y are the average of x and y, σ_x^2 and σ_y^2 are the variance of x and y, σ_{xy} is the covariance of x and y, $c_1 = (k_1 L)^2$, $c_2 = (k_2 L)^2$ are the 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.

6.3 SIMULATION RESULTS:

Bilateral Filter

A. Visual Results

Test Image : Einstein

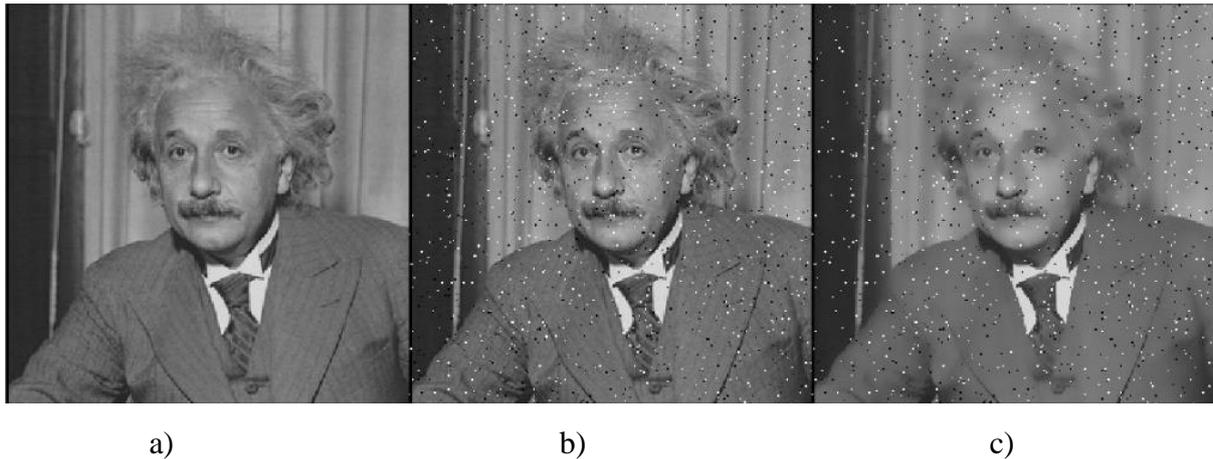


Fig 6.1 :Result of Bilateral Filter.

a)input image b)Noisy Image(salt and Pepper Noise with noise density 0.02) (PSNR:22.50)

c)After applying Bilateral Filter(PSNR:31.91)

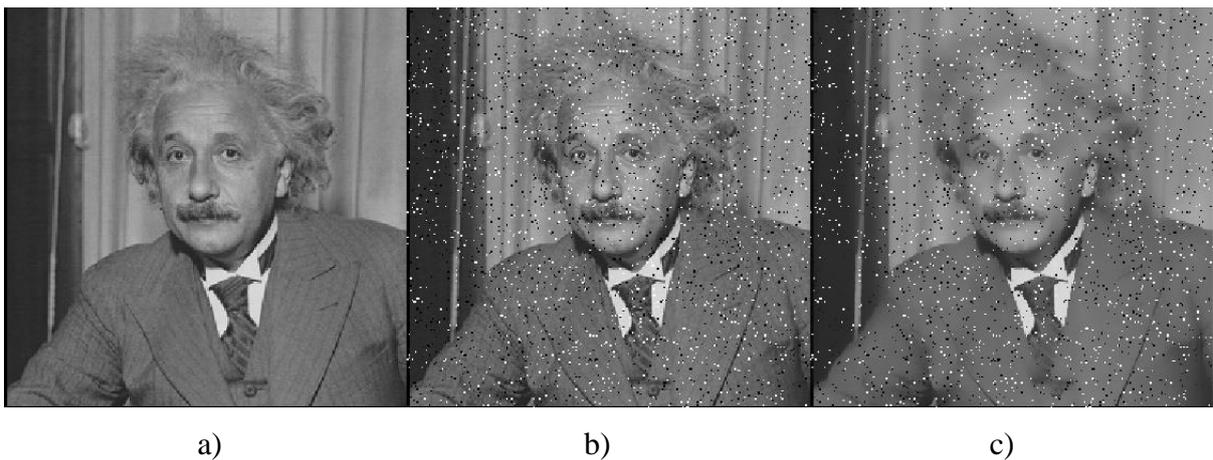
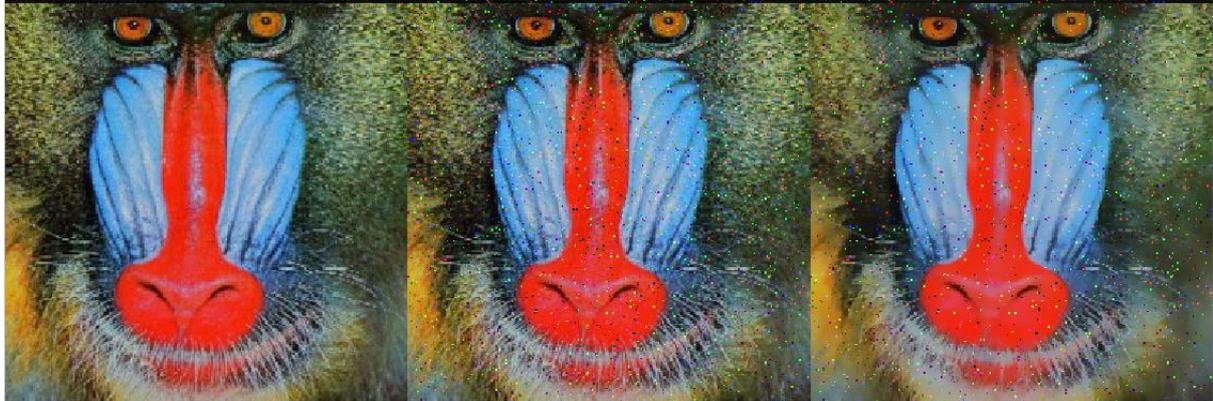


Fig 6.2 :Result of Bilateral Filter.

a)input gray image b)Noisy Image(salt and Pepper Noise with noise density 0.04) (PSNR:19.75)

c)After applying Bilateral Filter(PSNR:31.81)

Test Image : Mandrill



a)

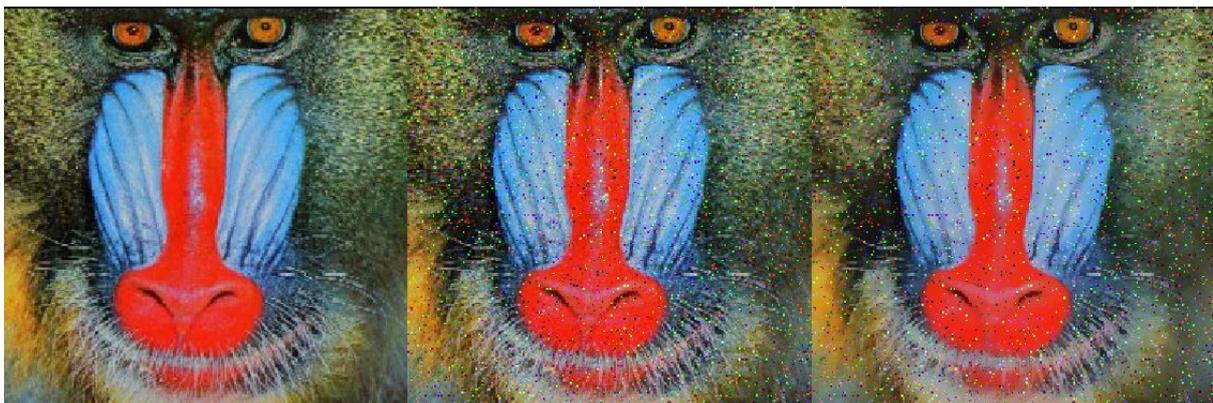
b)

c)

Fig 6.3 :Result of Bilateral Filter.

a)input colour image b)Noisy Image(salt and Pepper Noise with noise density 0.02)(PSNR:25.53) c)After applying Bilateral Filter(PSNR:30.28)

SSIM-0.908



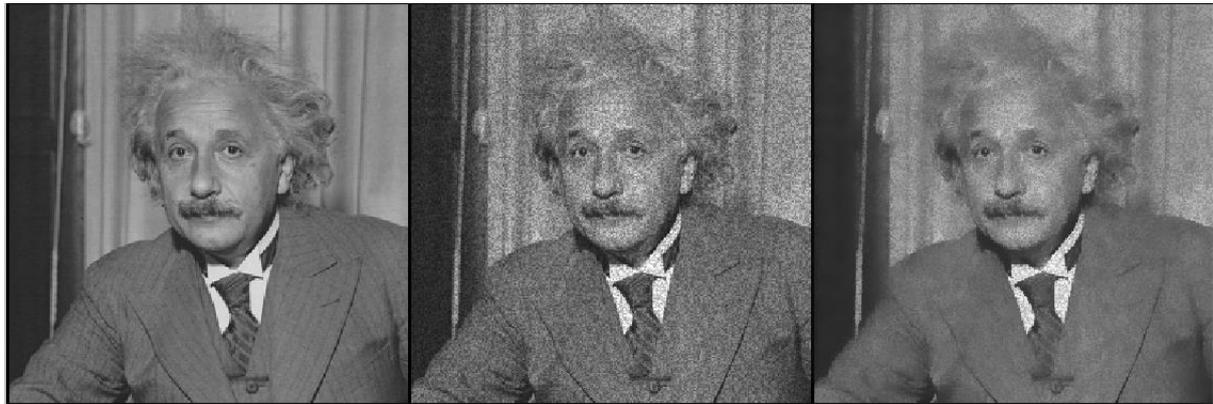
a)

b)

c)

Fig 6.4 :Result of Bilateral Filter.

a)input colour image b)Noisy Image(salt and Pepper Noise with noise density 0.04)(PSNR:18.71) c)After applying Bilateral Filter(PSNR:25.75)



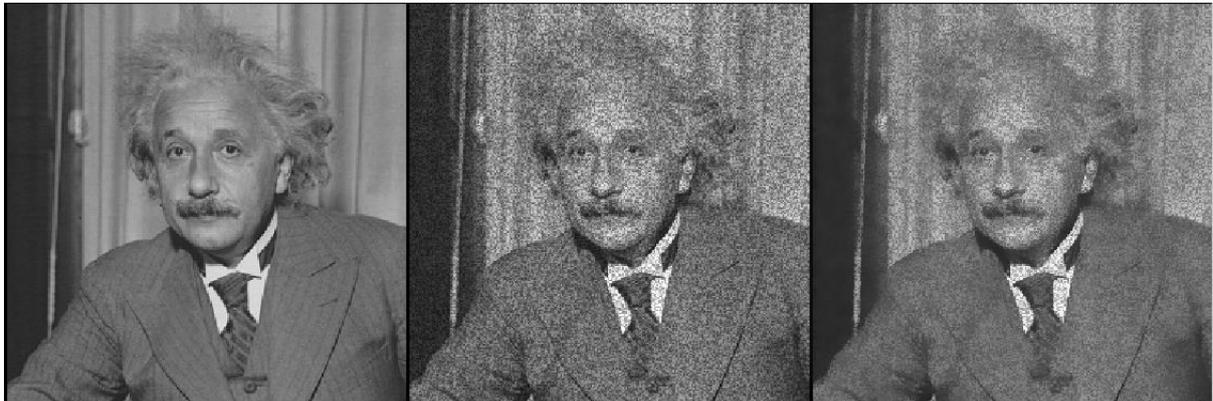
a)

b)

c)

Fig 6.5 :Result of Bilateral Filter.

a)input image b)Noisy mage(Speckle Noise with noise density 0.02)(PSNR:24.02) c)After applying Bilateral Filter(PSNR:28)



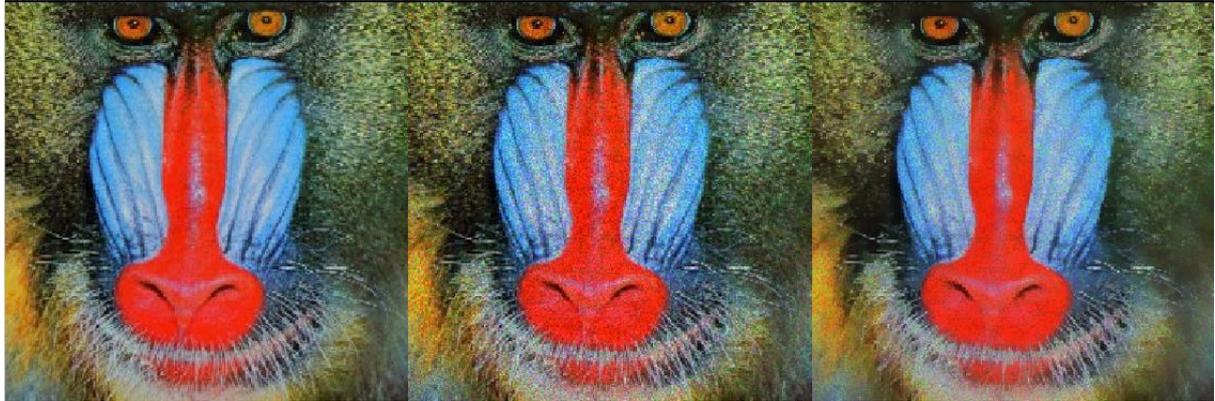
a)

b)

c)

Fig 6.6 :Result of Bilateral Filter.

a)input image b)Noisy mage(Speckle Noise with noise density 0.04)(PSNR:21.02) c)After applying Bilateral Filter(PSNR:24.59)



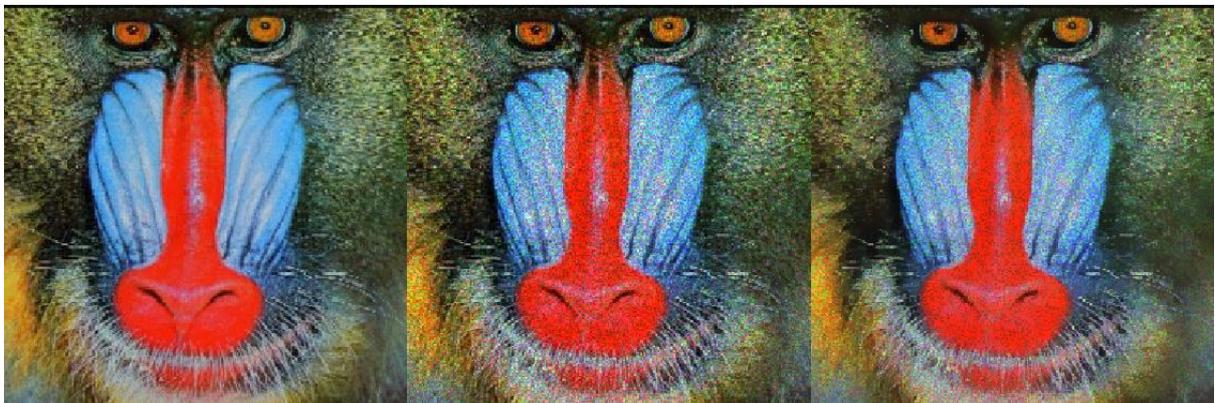
a)

b)

c)

Fig 6.7 :Result of Bilateral Filter.

a)input image b)Noisy Image(Speckle Noise with noise density 0.02)(PSNR:25.04) c)After applying Bilateral Filter(PSNR:29)



a)

b)

c)

Fig 6.8 :Result of Bilateral Filter.

a)input image b)Noisy Image(Speckle Noise with noise density 0.02)(PSNR:24.80) c)After applying Bilateral Filter(PSNR:27.32)

Guided Filter:

Test Image: Peppers

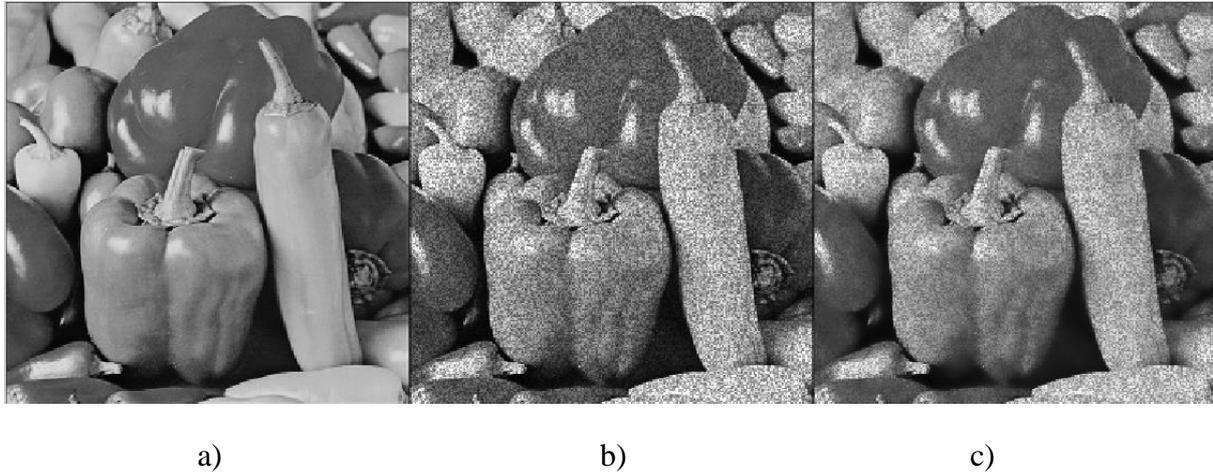


Fig 6.9 :Result of Guided Filter.

a)input image b)Noisy Image(Speckle Noise with noise density 0.05)(PSNR:20.07) c)After applying Guided Filter(PSNR:26.78)

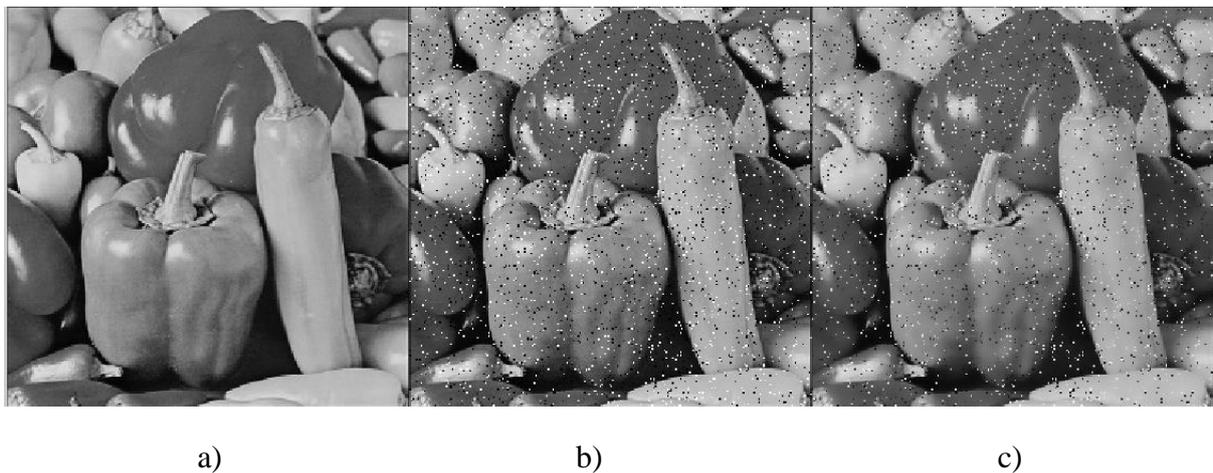


Fig 6.10 :Result of Guided Filter.

a)input image b)Noisy Image(Salt and pepper Noise with noise density 0.02)(PSNR:18,21) c)After applying Guided Filter(PSNR:23.33)

Hybrid filter:

Test Image : LENA



a)

b)

c)

Fig 6.11 :Result of Hybrid Filter.

a)input image b)Noisy Image(Salt and pepper Noise with noise density 0.02)(PSNR:18.21)

c)After applying Hybrid Filter(PSNR:30.33)



a)

b)

c)

Fig 6.12 :Result of Hybrid Filter.

a)input image b)Noisy Image(Salt and pepper Noise with noise density 0.02)(PSNR:15.21)

c)After applying Hybrid Filter(PSNR:32.78)

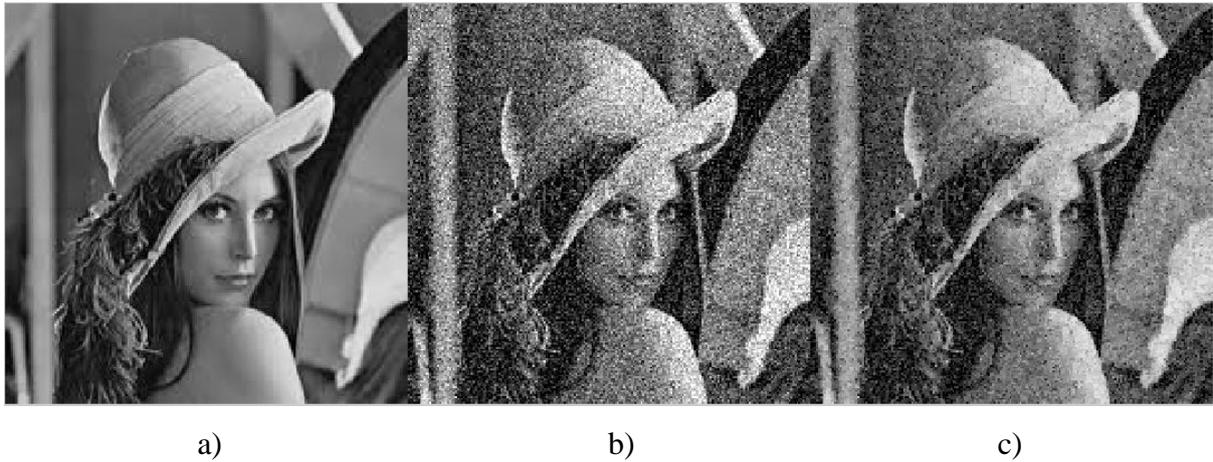


Fig 6.13 :Result of Hybrid Filter.

a)input image b)Noisy Image(Gaussian Noise with mean-0 and variance-0.02)(PSNR:17.02)
 c)After applying Hybrid Filter(PSNR:25.22)

The visual results obtained for the test images of Lena indicate that the proposed Hybrid Filter which makes use of intensity is better when compared to other edge preserving Filters

Table 6.1: Parameters Used

Component	Parameter	Value of parameter
Image	Image Size	256×256 pixel 512×512 pixel
	Type	RGB and Gray
Noise	Type	Gaussian Noise Salt and pepper noise Speckle noise Poisson Noise
	Variance of Noise	0.02-0.06
Software		MATLAB R2013a Modelsim Altera 6.4a

Table 6.2: Comparison of Performance Metrics of Bilateral, Guided and Hybrid Filter(Salt And Pepper Noise with Noise density 0.04)

TECHNIQUE	METRIC	IMAGES				
		Peppers	Einstein	Cameraman	Penguin	Lena
Bilateral Filter	PSNR	19.78	18.72	19.26	17.98	17.22
	SSIM	0.86797	0.8339	0.8525	0.82759	0.88252
Guided Filter	PSNR	21.44	22.13	21.46	20.28	21.64
	SSIM	0.92124	0.92569	0.92109	0.90394	0.92476
Hybrid Filter	PSNR	29.27	28.01	28.98	27.72	25.75
	SSIM	0.96451	0.98737	0.98988	0.93245	0.97951

Table 6.3: Comparison of Performance Metrics of Bilateral, Guided and hybrid Filter(Gaussian Noise Mean-0 and Variance-0.02)

TECHNIQUE	METRIC	IMAGES				
		Peppers	Einstein	Cameraman	Penguin	Lena
Bilateral Filter	PSNR	23.76	19.76	18.56	19.45	18.22
	SSIM	0.90666	0.86543	0.85355	0.79933	0.82756
Guided Filter	PSNR	25.52	22.20	20.42	20.68	20.20
	SSIM	0.92752	0.90233	0.89607	0.91029	0.89257
Hybrid Filter	PSNR	31.78	29.28	28.69	25.29	24.49
	SSIM	0.96146	0.97047	0.96105	0.95773	0.97052

From the above table, it can be inferred that there is a significant improvement in PSNR values of the proposed scheme when compared with bilateral and Guided Filters. SSIM values indicate that the similarity of the structural information is closer to that of the original image in case of the proposed scheme.

Results obtained From QUARTUS II:

Flow Summary	
Flow Status	Successful - Sat Nov 15 10:42:06 2014
Quartus II Version	9.0 Build 132 02/25/2009 SJ Web Edition
Revision Name	WLS
Top-level Entity Name	tab_9_ex1
Family	Cyclone III
Met timing requirements	N/A
Total logic elements	432 / 5,136 (8 %)
Total combinational functions	368 / 5,136 (7 %)
Dedicated logic registers	281 / 5,136 (5 %)
Total registers	281
Total pins	115 / 183 (63 %)
Total virtual pins	0
Total memory bits	0 / 423,936 (0 %)
Embedded Multiplier 9-bit elements	36 / 46 (78 %)
Total PLLs	0 / 2 (0 %)
Device	EP3C5F256C6

Figure 6.14 Flow summary report of Hybrid Filter

PowerPlay Power Analyzer Summary	
PowerPlay Power Analyzer Status	Successful - Wed Nov 26 10:12:59 2014
Quartus II Version	9.0 Build 132 02/25/2009 SJ Web Edition
Revision Name	WLS
Top-level Entity Name	tab_9_ex1
Family	Cyclone III
Device	EP3C5F256C6
Power Models	Final
Total Thermal Power Dissipation	120.04 mW
Core Dynamic Thermal Power Dissipation	15.91 mW
Core Static Thermal Power Dissipation	46.23 mW
I/O Thermal Power Dissipation	57.91 mW
Power Estimation Confidence	Low: user provided insufficient toggle rate data

Figure 6.15 Power analyzing report of Hybrid Filter

Slow 1200mV 85C Model Fmax Summary				
	Fmax	Restricted Fmax	Clock Name	Note
1	146.43 MHz	146.43 MHz	clk	

This panel reports FMAX for every clock in the design, regardless of the user-specified clock periods. FMAX is only computed for paths where the source and destination registers or ports are driven by the same clock. Paths of different clocks, including generated clocks, are ignored. For paths between a clock and its inversion, FMAX is computed as if the rising and falling edges

Figure 6.15 Speed analyzing report of Hybrid Filter

Table 6.4: The synthesis result of Bilateral, Guided and Hybrid Filter

Architecture	Bilateral Filter	Guided Filter	WLS Filter
FPGA Device	EP3C5F256C6	EP3C5F256C6	EP3C5F256C6
Total logic element	690	463	432
Total logic register	533	330	281
Multiplier element	36	28	16
Maximum Frequency	60.61 MHZ	109.09 MHZ	146.43MHZ

From the above table, it is very clear that the number of logic elements, multiplier elements and registers used are less than the other two filters which increases the efficiency of the Hybrid Filter.

CHAPTER 7

CONCLUSION AND FUTURE WORK

Image denoising is done with the help of Bilateral and Guided Filter at first which have disadvantages like gradient reversal and halo artifacts respectively. In order to overcome these disadvantages, Hybrid Filter (Weighted Least Square and Guided Filters) is used i.e. in an image for low intensity regions WLS algorithm is applied and for high intensity regions Guided Filter is applied. This Hybrid Filter can be used for filtering based feathering/matting and dehazing.

Here, the filter algorithms are simulated in ModelSim and the resultant images are viewed in MATLAB. The results of all the three filters are compared. The performance metrics like Peak signal to Noise Ratio and Structural Similarity Index are found. Also, area and power of the three filters are found in Quartus II. The simulation results clearly depicts that hybrid filter outperforms Bilateral and Guided Filters qualitatively and quantitatively.

In future, Hybrid Filter can be used for filtering video stream applications like surveillance, games and live broadcast.

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LIST OF PUBLICATIONS

Conferences

- Presented a paper titled “Image Denoising with the help of Bilateral and Guided Filters” in the IEEE sponsored 9th International Conference on Intelligent Systems and Control (ISCO’15) on 9th & 10th Jan,2015 held at Karpagam College of Engineering, Coimbatore.

Journal

- Published a paper in the title “Image Denoising with the help of Bilateral and Guided Filters” in the International Journal of Applied Engineering Research(IJAER)-Annexure II (ISSN 0973-4562 Volume 10 Number 1 (2015) pp. 1075-1078)