

Bilateral Filtering For Digital Images- A Review

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ABSTRACT: Bilateral Filter has amassed a great cognizance level in medical imaging, computer vision and graphics. Bilateral Filter is a non linear approach which takes into account not only the spatial distance between the pixels but also the differences termed as color intensity, range differences and for that reason it has been accounted as better at preserving the edges as well as textures in comparison to that of the conventional algorithms. Its capability to disintegrate an image into different scales without leading to any haloes has made it pervasive in computational photography applications such as tone mapping, style exchange and denoising. Digital images play a vital role in extensive variety of practices, for instance, Medical Imagery such as Ultrasound images, X-ray images and MRI Images. Images captured imbibe noise very easily from several sources and therefore the vital portion of Digital Image Processing involves restoration of images. It is a particular way of noise removal. Image denoising is an indispensable move which involves the modification of the image data to produce a visually high quality image. This paper presents the work analogous to the Bilateral Filter and certain variants to the Bilateral Filter.

KEYWORDS: Bilateral Filtering, Digital Images, Gaussian Convolution, Image Smoothing and Non Linear Filtering.

I. INTRODUCTION

Digital images play a crucial role in research and technology geographical information systems. Digital image acquisition and processing techniques play an extreme important role in modern medical diagnosis. Images of various living objects are captured using different techniques viz. Magnetic Resonance Imaging (MRI), X-Ray, Ultrasound and many more. During acquisition process, an image can have a lot of distortions and which in turn will affect the diagnosis of a patient based on that image. Hence it is of utmost importance that these distortions to be taken off using image processing techniques in order to increase the quality of this acquired image by reducing the level of noise which in turn will enhance the diagnosis. Even though there are variety of modalities present in medical domain, ultrasound images are largely used owing to their lower acquisition cost. In fact ultrasound images are the images which have high components of noise present in them when compared with the other extortionate methods such as MRI and CT. Medical images esp. Ultrasound images suffer from Speckle noise [1].

Bilateral Filtering has been prevalent in image processing due to its efficacy in noise reduction and preserving the fine structural details of an image at the same time. This attribute of preserving the details of an image results from nonlinear component of the filter. It opts for the intensity value of each pixel and it gets substituted by the weighted average of intensity values of the neighboring pixels. In this way it loops through each pixel and adjusts the weights. If we put it in nutshell we can say that it singles out all those pixels that are having same intensity level and those pixels are then averaged together by the linear component of the filter and thus protecting the sharp edges of the filter.

Bilateral Filter was firstly mooted by the C. Tomasi, R. Manduchi [2] in the year 1998. It is fundamentally a non-iterative, non-linear and edge-preserving technique which is used both for gray and color images and which preserves the edges while smoothing the image by reducing noise at the same time. It is a well known fact that color images have three bands viz. red, green and blue. If these three bands are filtered one at a time then there are high chances that

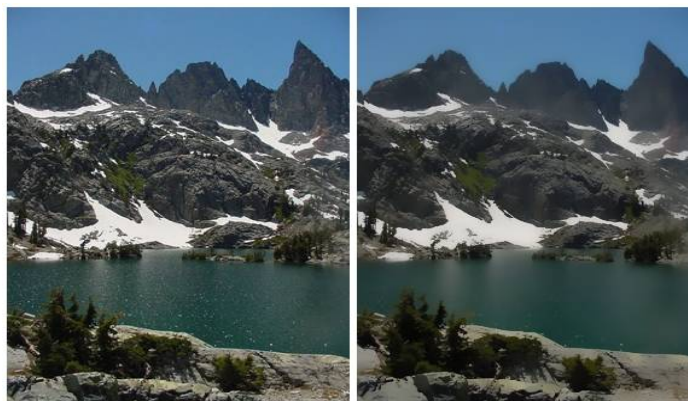
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unanticipated color combinations would appear across the edges and the smoothness of the image at the edges would be different. Individual smoothing disturbs the equilibrium of the colors. Hence, Bilateral Filters operate on all the three band of color at the same time and can tell which colors are similar so that they can be averaged concurrently [2]. Bilateral Filtering algorithm is a non-linear and non-iterative image de-noising modality in spatial domain which brings into account the geographical location of all pixels as well as the information of disparities in intensity values between a pixel and its neighbors to smooth the corrupted images while keeping the edges intact very well. The Bilateral Filter is opted for one remarkable rationale: it alleviates noise while keeping fine structures intact.



(a)

(b)

Figure 1: (a) Original image (b) Image processed with Bilateral Filter removing noise, smoothes texture but preserves large sharp edges without blurring.

The bilateral filter incorporates the objective of the combination of domain and range filtering. The domain filter executes the averaging of all those pixels that are neighbors of each other and hence behaving as a low pass filter. The range filter comprises the nonlinear component and executes an essential part in keeping edges intact. This component considers averaging of only those values of pixels that are similar to each other and it does not matter where they are geographically located in the filter window. If the pixel value in the filter window deviates from the pixel value that is being filtered by a certain amount, the pixel is skipped. It replaces each pixel with the filtered value irrespective of the fact whether it is noisy or not [3].

Image Denoising is the most crucial step in Image Processing and computer vision applications [4]. Images that we pick either from digital cameras or from conventional film cameras, both acquire a certain amount of noise in them. Denoising method is problem specific and relies mostly on the type of image to be processed and the noise model. Different noise models and noise types exist [5].

There are mainly two types of noise models found in images namely Additive form and Multiplicative form.

1) Additive Form

Noise signal that is additive in nature adds itself to the input original image and induces distortions into the image and relies on the model:

$$w(x, y) = s(x, y) + n(x, y) \quad (1)$$

2) Multiplicative Form

Noise signal that is multiplicative in nature multiplies itself to the input image and relies on model:

$$w(x, y) = s(x, y) * n(x, y) \quad (2)$$

Where $s(x, y)$ is the genuine intensity of an image and $n(x, y)$ represents the noise introduced to result a distorted signal $w(x, y)$ at (x, y) pixel location [6].

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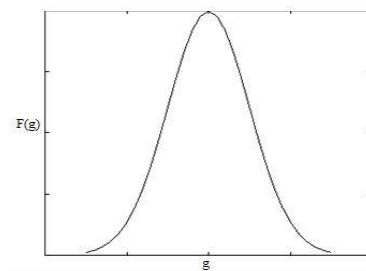
Different types of noises have different characteristics. The types of noises that are found in digital images are explained as follows [6].

1) Gaussian Noise

Gaussian noise spreads uniformly over the entire image which means every value of the pixel in an image is an inclusion of genuine value of the pixel and the Gaussian distributed value of noise. In this noise, every value of the pixel gets altered from its authentic value by conventionally small quantity. This noise has distribution which is Gaussian in nature and the bell shaped probability density function is expressed as:

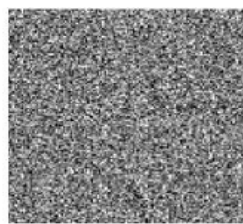
$$F(g) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(g-m)^2}{2\sigma^2}} \quad (3)$$

Where g expresses the gray level, m represents mean or average of the function and σ is the standard deviation of the noise. Its graphical representation is as follows:

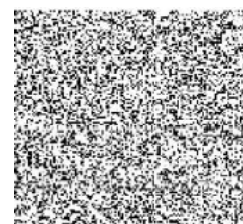


(a)

When a Gaussian noise is introduced into an image, Gaussian noise with mean 0 and variance as 0.05 would look as image (b) and image (c) represents Gaussian noise with mean 1.5 and variance as 10 over a base image with constant pixel value of 100.



(b)



(c)

Figure 2: (a) Gaussian distribution (b) Gaussian noise with mean= 0 and variance = 0.05 (c) Gaussian noise with mean= 1.5 and variance= 10.

2) Salt and Pepper Noise:

It is of impulsive nature. The image corrupted with this noise often embeds in itself dark and white dots and hence the name salt and pepper. Every individual pixel in the distorted image varies from its neighboring pixels in terms of color or intensity. The prime reason of occurrence of this type of noise is impairment of the elements of pixel in camera sensors, errors that occur during the transmission of data or it could be the timing errors in digitization. Image (a) represents its probability density function. The pixels affected either take maximum value or minimum value thus giving “salt and pepper” like appearance. For an 8-bit image, value for pepper noise is 0 and value for salt noise is 255.



Figure 3: (a) probability density function of "salt and pepper" noise (b) "salt and pepper" noise when introduced into an image.

3) Speckle Noise:

Its nature is multiplicative. This modality of noise occurs in well-nigh all coherent imaging systems viz. laser, acoustics and SAR (Synthetic Aperture Radar) imagery. Speckle noise is very much predominant in medical diagnosis esp. Ultrasound imagery. The origin is accredited to the random interference that occurs between the coherent returns. It follows gamma distribution and is given as:

$$F(g) = \frac{g^{\alpha-1}}{(\alpha-1)!a^\alpha} e^{-\frac{g}{a}} \quad (4)$$

Where variance is σ^2 and gray level is g . It follows gamma distribution.

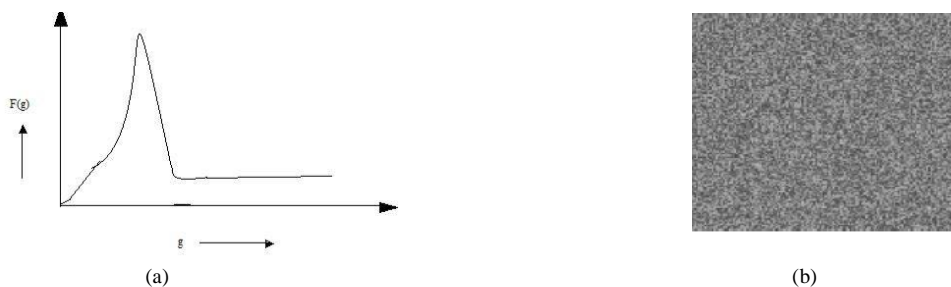


Figure 4: (a) Gamma distribution (b) speckle noise (with variance 0.05)

4) Brownian Noise:

Brownian noise, also termed as Brown noise or red noise falls under the domain of 1/f noises and Brownian noise is the special case of these noises. It is attained by the integration of the White noise. Brownian noise introduced into an image looks as shown in Fig. 5



Figure 5: Brownian noise

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The quantity of reduction of noise through weighted averaging process and the quantity of blurredness through low-pass filtering are both regulated by two parameters. There are numerous applications in image processing domain such as Denoising, Texture and Illumination Separation, Tone mapping and Tone management, depth reconstruction, Data fusion and 3D Fairing where it is paramount to remove noise in the images before accomplishing these techniques.

Bilateral Filter is used as a standard tool for denoising and in the wake of this it has become well-accepted in computer graphics community [7]. Bilateral Filtering an image will break up an image into smaller textures or features and the application of texture and illumination separation will redraft each component individually in order to calibrate the tonal distribution or to fit the image as per the display device.

Tone mapping is a beautiful application that compresses the intensity values of a high dynamic range image to be competent enough to fit in the abilities of a low dynamic range image. Bilateral Filter uncouples the small textures without bringing any kind of haloes into the image [8].

The Data Fusion application of Bilateral Filtering takes into account the combination of a flash and a no-flash image. This work has been stimulated by the fact that albeit the flash image is very unpleasant to the eyes, its signal to noise ratio is greater than the no-flash image. On the contrary to that, no-flash picture is delightful to eyes and has a natural look, but its high frequency components are distorted. The key idea is to draw out the details from the flash photograph and integrate it with the no-flash photograph and a variant of Bilateral Filter performs this task [9].

The application of Bilateral Filtering in 3D Fairing, it is applied to 3D meshes and it smoothes the images by removing noise from them and yet keeps the edges, seams and corners intact and sharp.

The rest of the paper is organized as follows: Section II gives brief idea about the related work in the domain of Bilateral Filter. Section III presents linear Gaussian Filtering i.e. Image smoothening with Gaussian Convolution. Section IV presents edge preserving filtering with Bilateral Filter. Section V explains various existing techniques for removing noise from images. Section VI gives conclusion and References are in Section VII.

II. RELATED WORK

Various types of procedures have been put forward in the past for removing various types of noises from an image. Zhang et al. (2008) proposed Adaptive Bilateral Filter. For 3D gray scale image it's very complex and time-taking but on the contrary to that Bilateral Filter gives better results as it preserves the edges of the image as well as corners and tenuous details in the input image while smoothing the image [10].

Chaudhury et al. (2011) proposed a bilateral filter realized by using trigonometric range kernels. For a certain number of terms approximation acquired with the help of trigonometric kernels was of higher-caliber to that done by polynomials but it cannot filter the sharp edges of the image [11].

Gunturk (2011) proposed a bilateral filter with arbitrary range and domain kernels, which led to an increase in computational complexity [12].

Zhang et al. (2012) proposed joint bilateral filtering which comprises digital photography approach and comprises flash-no flash image pairs. Although flash picture is very unpleasant to eyes and has hard-looking lighting, its signal to noise ratio is greater than that of no-flash image. On the opposite, a no-flash image is more delightful to eyes owing to the fact that it is naturally looking, but its high frequency components are distorted by noise. The key goal is to extract ALL the essential fine details from the flash photograph and to merge it with the non-flash photograph. And this task is executed with the use of Joint Bilateral Filtering [13].

Mahesh Mohan M R et al. (2013) proposed contourlet transform as a step which will be executed as a preprocessing step on Bilateral Filtering or on NLM filtering. It utilized CT image of abdomen and MRI image of brain. It is superior approach when it comes to calculating PSNR and perceptual quality in comparison to that of Bilateral Filtering or NLM denoising performed alone [14].

Jith et al. (2014) proposed non local means bilateral filtering which performs well only on high noise images [15].

Sugimoto et al. (2015) proposed compressive bilateral filtering which is fruitful only against range kernels that are having narrowband spectrum namely Gaussian range kernel because of the compression with the help of the Fourier series [16].

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Papari et al. (2016) has proposed fast implementation of bilateral filtering by optimal expansion of the filter kernel. This method leads to much faster convergence than similar algorithms aimed at improving the speed of bilateral filter and preserves edges while smoothing an image [17].

III. SMOOTHENING OF AN IMAGE USING GAUSSIAN CONVOLUTION

Blurring is maybe the least complex approach to smooth a picture; every value of the pixel in the output image is a weighted aggregate of its neighbours in the information picture. The central constituent is the convolution by a kernel which is the fundamental task in linear shift-invariant image filtering. At the every location of the output pixel, it evaluates the neighbouring intensities average and corresponds to low-pass filtering. An image that can be filtered with the help of Gaussian Convolution is expressed as:

$$GC[I]_p = \sum_{q \in S} G_\sigma(\|p - q\|)I_q \quad (5)$$

Where $G_\sigma(x)$ denotes the 2D Gaussian kernel shown in Figure 7.

$$G_\sigma(x) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2}{2\sigma^2}\right) \quad (6)$$

Gaussian filtering is a result of weighted mean of the intensity of the neighbouring locations with a weight diminishing in proportion to that of the spatial separation to the centre position \mathbf{p} . The weight for pixel \mathbf{q} is defined by the Gaussian $G_\sigma(\|p - q\|)$, where σ is a parameter defining the neighborhood expanse. The gauge of this influence depends only on the path chosen to move from one pixel to the other and not their values. For example, a brilliant pixel has a solid impact over a contiguous dim pixel in spite of the fact that these two pixel qualities are very different from each other. In the wake of this, the edges of the picture attain blurredness owing to the fact that averaging of the pixels has taken place across the discontinuities as in Fig. 6.

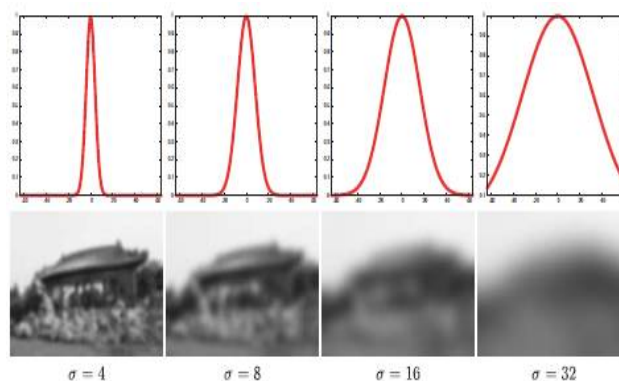


Figure 6: Filtering with the use of Gaussian Convolution at various values of σ .

Top row in Fig. 6 depicts the profile of a 1D Gaussian kernel and bottom row depicts the result attained by the corresponding 2D filtering with the help of Gaussian Convolution. Edges vanish when we go for greater values of σ owing to the fact that averaging gets performed at much larger area. The task of the Gaussian convolution is autonomous of the details of the picture. The impact that the pixel has on another pixel depends just on the distance between them and not their real values.

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IV. FILTERING THAT INVOLVES PRESERVING EDGES USING BILATERAL FILTER

The Bilateral Filter is also characterized as a weighted mean of adjacent pixels, in a way very alike to Gaussian Convolution. The distinction lies in the fact that the Bilateral Filter considers the disparity in value as compared to that of neighbors to save edges as well as smoothing the image. The main thought of the Bilateral Filter is that for a pixel to impact other pixel, it ought to possess a nearby location as well as closer value. The representation of this thought traces back in the literature to Aurich and Weule [18], Smith and Brady [19] and Tomasi and Manduchi [1]. The Bilateral Filter BF $[I]_p$ is defined by:

$$BF[I]_p = \frac{1}{W_p} \sum_{q \in S} G_{\sigma_s}(\|p - q\|) G_{\sigma_r}(|I_p - I_q|) I_q \quad (7)$$

Where normalization factor W_p makes certain sum of weights of pixels to 1.0:

$$W_p = \sum_{q \in S} G_{\sigma_s}(\|p - q\|) G_{\sigma_r}(|I_p - I_q|). \quad (8)$$

Parameters σ_s and σ_r will depict the quantity of filtering for the image I . Equation of $BF[I]_p$ is a normalized weighted mean where G_{σ_s} is a spatial Gaussian weighting that diminishes the impact of pixels that are away, G_{σ_r} is a range Gaussian that diminishes the impact of pixels q when their intensity values differ from I_p .

The various characteristics of Bilateral Filter are explained as follows:

1) Parameters required

The Bilateral Filter is mastered by two parameters: σ_s and σ_r . These parameters will depict the quantity of filtering for the image. σ_s Corresponds to the spatial parameter and σ_r corresponds to the range parameter. Fig. 7 delineates their impact. As the range parameter σ_r moves to a higher value the Bilateral Filter gradually approximates Gaussian Convolution more closely owing to the fact that the range Gaussian G_{σ_r} widens and flattens, i.e. it is well-nigh uniform over the entire intensity interval of the picture. On Expanding the spatial parameter σ_s bigger features get smoothed.

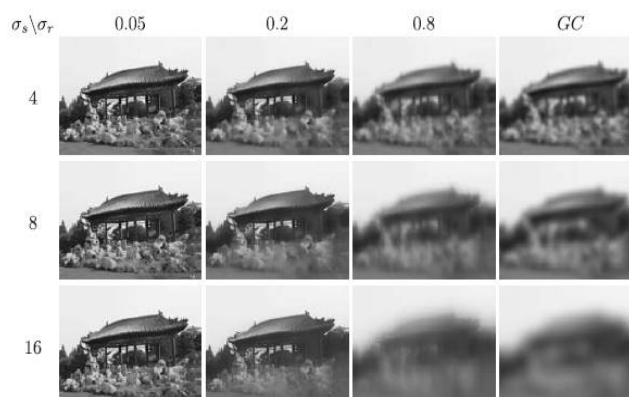


Figure 7: Parameters effect (σ_s and σ_r)

A striking feature of Bilateral Filtering is that the weights get multiplied: if any of the weights is near zero, no smoothness would occur. For instance, a huge spatial Gaussian combined with slender range Gaussian accomplishes constrained smoothness in spite of the fact that there is huge spatial expanse. The range weight implements a severe protection of the contours.

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2) Reckoning Cost

Bilateral Filter is an expensive algorithm to quantify when the spatial parameter σ_s is large owing to the fact that every result of a pixel results from the neighborhood, requires the computation of two weights, their items, and an exorbitant normalizing venture also.

3) Repetition of Process or Iterations

The Bilateral Filter can repeat its process i.e. it can be iterated. This produces results that are practically piecewise consistent as appears in Fig. 8. In spite of this fact that the iteration process results smoother pictures, this outcome is not quite the same when we opt to expand the value of spatial as well as range parameter. Fig. 8 shows that expansion of the spatial parameter σ_s has a restricted impact unless the range parameter σ_r is likewise expanded.

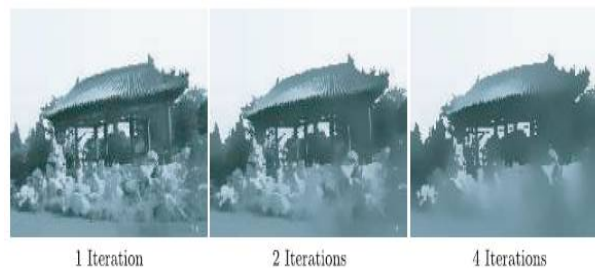


Figure 8: The iterations in bilateral filter, giving cartoon like revamp of image. Here $\sigma_s = 8$ and $\sigma_r = 0.1$.

Although if we go for higher value of σ_r , it additionally leads to the smoother yields but obscures the edges as can be seen from Fig. 8 which in turn leads to the removal of the fine details. This kind of impact is alluring for applications, for instance, stylization whereas computational photography strategies seek to abstract the fine details of interest and because of that these strategies opt for not repeating the process and to go for single iteration to be closer to the original image details.

4) Disintegration of a picture into filtered and residual parts

The Bilateral Filter can break up a picture in two sections: a picture that has been filtered by the filter and the residual one. The filtered picture contains just the large-scale features, because the Bilateral Filter smoothed away local variations without creating any impact on the solid edges.



Figure 9: Filtered and residual image by Bilateral Filter

The residual picture results when we subtract the filtered picture from the original picture and it embeds in it the portion that has been removed by the filter. Depending on the settings and the requirement, this expelled little scale part can be elucidated as noise or texture, as shown in Fig. 9 [7].

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V. ANALYSIS OF EXISTING METHODS

Image Denoising is an indispensable step and therefore a lot of research is available in this domain. The various existing methods are explained Table1.

Table 1: Denoising Methods

Method	Remarks
Gaussian Filter	It Acts as a low pass filter. It Blurs the images and removes noise as well as fine details.
NLM Denoising	It is based on non-local averaging of all pixels in image. It blurs edges and other image details.
Anisotropic Diffusion	Images get smoothed while edges are preserved but it involves the solution of Partial Differential Equations (PDE's) which makes it complex. Bilateral Filter has been proposed as a non iterative alternative.
Bilateral Filter	Image gets smoothened while edges are preserved. It does not involve the solution of PDE's and can be implemented in single iteration. Variants of Bilateral Filter have been proposed.
Adaptive Bilateral Filter	It becomes very complex and time taking for 3D gray scale image.
Bilateral Filter by using trigonometric range kernels	For fixed no of terms the approximation obtained using trigonometric kernels was superior to that done using polynomials. It cannot filter sharp edges of an image.
Bilateral Filter with arbitrary range and domain kernels	It leads to an increase in computational complexity
Joint Bilateral Filtering	It works for flash and no-flash image pairs and yields high-performance at a fast speed suitable to variety of computer vision applications.
Contourlet transform as a pre-processing step on Bilateral Filtering and NLM filtering	It yields superior PSNR results as compared to Bilateral Filtering or NLM denoising done alone.
Non local means Bilateral Filtering	It works well only on high noise images.
Compressive Bilateral Filtering	It is effective only against range kernels with narrowband spectrum.
Fast Bilateral Filtering	It leads to much faster convergence than similar algorithms aimed at improving the speed of Bilateral Filter. It preserves edges and fine details while smoothing the image.

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VI. CONCLUSION

Image denoising is an indispensable step in the domain of Image processing and computer vision applications. Digital images tend to acquire noise from various sources and various techniques have been propounded for Image denoising. The aim of restoring images by preserving their edges as well has been approached with the help of partial differential equations (PDE's) for so many years. Bilateral Filter has been put forward as a non-iterative substitute to Anisotropic Diffusion, which requires the solution of partial differential equations. In both these techniques, images are smoothed and at the same time preserving of edges is also done. Unlike Anisotropic Diffusion, Bilateral Filter does not contain the solution of PDE's and can be executed in a single iteration.

Later, variants to Bilateral Filter have been put forward and their usage is absolutely application specific. To put in a nutshell, Bilateral Filter is a successful way to smooth an image while preserving its disruptions and also to disintegrate image structures of different scales. Bilateral Filter has variety of applications and its chief goal of allocating weights that rely on both space and intensity can be customized to fit into large expanse of applications.

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