Performance Analysis of Image Smoothing Methods for Low Level of Distortion

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***Abstract*— Image enhancement is an initial and basic preprocessing step in image processing. The success of this primary module determines the accuracy rate of higher level of image processing task. This module is application specific in nature. So determining a suitable image enhancement for real time images is a challenging one. Common distortions that are found in the real time images are contrast variation, blur, salt and pepper noise and so on. It is a challenging task to enhance the low level of blur distortion in an image. Hence in this paper the existing image smoothing methods (mean filter, Gaussian filter, anisotropic diffusion, median filter, adaptive median filter, conservative smoothing, and alpha trim mean filter) suitable to enhance low level distortion in images are evaluated in detail. Images of low distortions along with its ground truth image were taken from the CSIQ dataset. Performance of the existing image smoothing methods was measured using Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM). Results showed that PSNR and SSIM were higher for conservative smoothing method followed by the adaptive median filtering method. Hence, this study concludes that conservative smoothing technique and adaptive median smoothing among neighborhood processing techniques could be deployed as a suitable image enhancement algorithm for blur effect removal.**

Keywords*— Image enhancement, Image smoothing, Quantitative analysis

I. INTRODUCTION

Image enhancement module play an important role as the impact of this phase determines the accuracy of higher level tasks of image processing [1, 2]. Images are easily prone to different type of distortions [3, 4]. Especially there are more possibility for distortions like contrast variation, blur, Gaussian noise, salt & pepper noise and so on. Blurring effect is a common distortion that is usually found in most of the images. Enhancing the low level distortion due to blur is a challenging task. In general image enhancement tasks are used to improve the image quality to high perception either through spatial domain or frequency domain. In spatial domain the manipulations are directly carried out in the pixel values and vice versa for frequency domain where it is indirectly manipulated through transformations. Point processing and neighborhood processing are the two important methods of spatial domain methods are considered to be suitable for real time image manipulation than the frequency domain methods. In point processing method, an image is enhanced by performing direct manipulation over each pixel.

In neighborhood processing or spatial filtering method, an image is enhanced by applying a mathematical function to each pixel in an image along with its neighboring pixels. Correlation and convolution are two important terms in spatial filtering. Correlation determines the degree of likeness among data set in which the kernel is moved over entire pixels in an image and the predefined manipulation is performed in each pixel position. Image convolution is similar to correlation except the fact that spatial mask is rotated to 180 degree before performing manipulations. Image convolution operation is used widely for enhancing effects (like blurring, edge sharpening etc) in the images. The main idea behind spatial filtering is to combine the mathematical function and convolution mask for enhancement. This combined performance of convolution and mathematical function is technically termed as filtering. It is mainly used for the purpose of eliminating the unwanted or repetitive information in an image. Filtering techniques used for the manipulation of images in spatial domain are referred as spatial filters which are either linear or non-linear. Linear filters modify the targeted pixel value by using specific linear combinations of the neighborhood pixel values whereas non-linear filters use any non-linear combinations of neighborhood pixels for modification. Filtering mechanism is done usually by calculating the product of all pixel elements in the kernel along with its corresponding pixel elements in the neighborhood of the target pixel and to sum up all these products. The kernel or window or mask (usually rectangular in shape) is moved over entire pixels in an image to perform the predefined operation in each pixel value to attain a new enhanced pixel value for the entire image. Two main aspects that are considered to be essential in image enhancement are image sharpening and image smoothing. In Image sharpening, image information is detailed in such a way that it contains high spatial components of the image. In Image smoothing, image information is reduced such that it contains low spatial components of image. In this paper the existing image smoothing methods suitable to reduce the blurring effect in an image are examined and evaluated.

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II. IMAGE SMOOTHING

Image smoothing is a local preprocessing method used to suppress the noise (i.e., unwanted information) and to blur (i.e., removes small details) the image. It is very much effective to remove impulse noise in an image. It reduces the high frequency components in an image and retains low frequency components to smooth the image [5, 6]. It removes the higher frequency information by blurring the image. Image smoothing has more effect of smoothness as the window size of mask is increased but has a disadvantage that the required image features are removed. The input image in RGB color space must be converted into gray-scale to make the image suitable for preprocessing as in Fig. 1. In this paper, the low level distortion of blur effect is focused and these images are considered for analysis as in Fig. 2.There are different linear and non-linear filters used to enhance the image using smoothing filters and some of these commonly used filters are as follows;

Fig. 1. Three sample original images taken.

Fig. 2. Low level distorted images of Fig. 1.

A. Mean or Average filtering

Mean filtering is a simplest linear spatial filter used to smooth images for noise suppression by reducing the variations in pixel intensities as in Fig. 3. This method is similar to the convolution concept used in spatial domain. Filtering kernel is square in shape like 3x3, 5x5 for sliding over the entire image. In this technique, center pixel value in the kernel is replaced by a new pixel value as mean of its neighboring pixels along with itself. This method is effective in removing noise but high frequency information in the image is lost. Quality of image is degraded when large size of kernel is applied over the image.

Fig. 3. Output of average filtering method for the input images of Fig. 2.

B. Gaussian Filtering

Gaussian filtering is a linear spatial filter used for smoothing thereby reduces the noises in an image like mean filters as in Fig. 4. This method is best suited for Gaussian noise removal and it uses a bell-shaped 2-D Gaussian kernel for changing the pixel values. The 2-D Gaussian function is defined as,

$$f(s,t) = \frac{1}{2\Pi\sigma^2} e^{-(\frac{s\ +t^2}{2\sigma^2})} \tag{1}$$

Where 'σ' is the standard deviation for a function 'f' with coordinates, 's' and 't'.

Standard deviation and kernel size are two major parameters in this filter. Standard deviation controls the smoothing result where larger the standard deviation value requires larger convolution kernel. This value suppresses high frequency information in an image and is referred as low pass filters. In contradiction to mean filter, it uses weighted average in the kernel for changing the center pixel value. This Gaussian filter is considered as a primary step in canny edge detector for noise suppression and is well suited for analysis in the frequency domain analysis.

Fig. 4. Output of Gaussian filtering method for the input images of Fig. 2.

C. Anisotropic Diffusion filtering

Anisotropic or Persona-Malik diffusion is a nonlinear and space variant partial differential equation (PDE) proposed by Persona & Malik for the purpose of enhancement and segmentation of image [7, 8]. Preservation of edges without any information degradation in an image is the main advantage of this method as in Fig. 5. The PDE based anisotropic diffusion equation is expressed as,

$$\partial K_i = div(A(\|\nabla x\|)\nabla x) \tag{2}$$

where 'x' is a 2-D gray scale image. 'div' represents divergence operator and '' represents smoothed image 'x' at step 'i'. '$\|\nabla x\|$' is the image gradient magnitude and '$A(\|\nabla x\|)$' is a function for function. If the function approaches towards zero, then the gradient magnitude value reaches its infinity and will not affect the edges. Hence diffusion process is done only in the interior region of an image to get a better smoothed image [9]. Major disadvantage of this method is that there are more probabilities for divergence during the evolving process of diffusion. Bias has been added to the existing equation to resolve this issue. Another drawback is its inability to distinguish high gradient fluctuations in the noise from the edges.

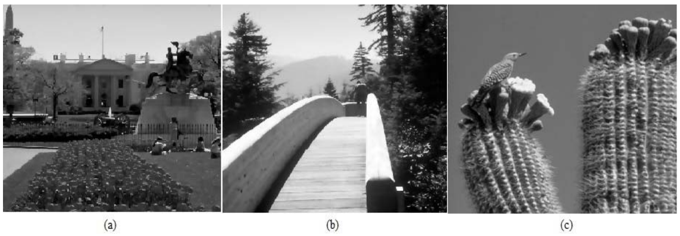

Fig. 5. Output of anisotropic diffusion filtering method for the input images of Fig. 2.

D. Rank filtering

Order statistics or rank filtering is a non-linear spatial filter in which the center pixel value of the kernel is changed based on the ordering or ranking of pixels in the kernel region. These values are arranged in the ascending order for performing neighborhood operation. Max, min and median are some of the common non-linear ordering filters considered for enhancement. Max filters uses the 100th percentile value or maximum value of the kernel in the center pixel value of the kernel whereas median filters uses the 50th percentile pixel value and min filters uses the 0th percentile or minimum value to change the center pixel value of the kernel.

E. Median filtering

Median filter is a rank filtering method which is capable to reduce the irrelevant and vague information in an image. It also preserves high frequency details in an image unlike mean filters as in Fig. 6 [10]. This method also uses square shaped kernels like 3x3 and 5x5 for changing the pixel values. Median value is calculated for the kernel and its corresponding center pixel value is substituted by this median value. Median value is calculated by sorting the entire pixels in kernel either in ascending or descending order. Therefore this filter is also termed as order static filter or rank filter. This kernel is moved over the entire image to get an enhanced image for interpretation. Removal of noise with less degradation in an image is the main advantage of median filtering. Computational time is expensive in this method as it requires ordering of numerical data in the kernels. This method is very much suitable for eliminating the impulse or salt and pepper type noise from an image.

Fig. 6. Output of median filtering method for the input images of Fig. 2.

F. Adaptive median filtering

Adaptive median filter is also a rank filtering method used to remove the impulse noise without reducing or removing any high frequency information in an image [11]. This is an efficient and advanced technique when compared with the standard median filters. Preserving the detailed information of an image even during the smoothing process is a main advantage of this method. Unlike other filtering techniques, this method is capable to change or modify the pixel kernel size and threshold criteria during the manipulation process. Major purpose of this method is to reduce the distortion and to remove the impulse noises by smoothing the image without any loss of information as in Fig. 7. Smaller the window size, lesser the loss of information during smoothing process in an image and vice versa for large window size in which there is high loss of information during the smoothing process.

Fig.7.Output of adaptive median filtering method for the input images of Fig. 2.

G. Alpha trimmed mean filter

It is considered as a non-linear filtering technique which combines both mean and median filters. It is similar to average filtering by the manner it calculates average value of pixels with its neighborhood in the kernel. It combines the concept of order statistics to improve the filtering performance. It uses the median filter to arrange the neighboring pixels in ascending order and to set an alpha value for trimming the pixels. This alpha value removes extreme minimum and maximum value in the kernel to have an optimized output from filtering as in Fig. 8. Alpha trimmed mean filter is performed using the formula,

$$ATMF = \frac{1}{(n^2 - 2\alpha)} \sum_{i=\alpha+1}^{(n^2-\alpha)} M_i \tag{3}$$

$$\alpha = \frac{(n^2 - 1)}{2} \tag{4}$$

where 'M_i' is a square mask with a size of 'n x n' and 'α' is any value within the range of 0 to median. If the alpha value is zero, then the filtering technique acts like mean filter. If the alpha value is calculated from the below formula, then the filtering technique acts as a median filter. Alpha trimmed mean filter is best suited for images which are distorted by both the type of Gaussian and salt & pepper noise.

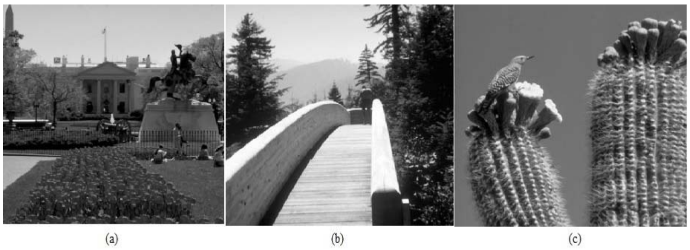

Fig. 8. Output of alpha trim mean filtering method for the input images of Fig. 2.

H. Conservative smoothing

Conservative smoothing is a filtering technique that preserves high frequency information but has less noise suppression capability as in Fig. 9. This method is effective towards noise spikes but is weak towards additive noise. It is a simple and fast filtering technique that takes the range of pixels between maximum and minimum value in the kernel excluding the target pixel taken for comparison. If the target pixel lies outside the range and if it is greater/ lesser than the maximum/ minimum then it is replaced by the maximum/ minimum value else the pixel value remains unchanged. Similarly this concept is done over the entire image region to get a better enhanced image.

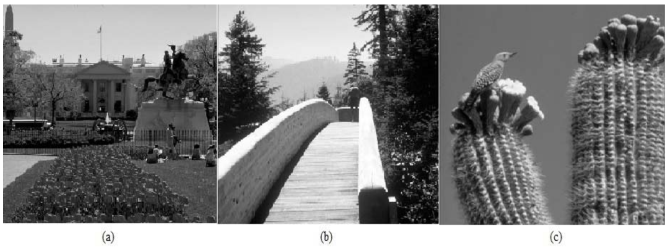

Fig. 9. Output of conservative smoothing method for the input images of Fig. 2.

III. Performance Evaluation

Images are taken from the CSIQ dataset to experiment the performance of existing image smoothing methods towards low level of distortion caused in an image due to blur as in Fig. 10 [12]. The different smoothing methods like mean filter, Gaussian filter, anisotropic diffusion, median filter, adaptive median filter, conservative smoothing and alpha trim mean filter were evaluated. The output of these methods must be evaluated objectively. So the popularly and commonly used quality assessment techniques like Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM) were calculated for enhanced images achieved through different neighborhood methods [13, 14]. PSNR and SSIM of image smoothing methods (mean filter, Gaussian filter, anisotropic diffusion, median filter, adaptive median filter, conservative smoothing and alpha trim mean filter). PSNR is used to measure the error sensitivity information between the enhanced and the distorted image. SSIM is used to measure the structural information between the enhanced and distorted image. PSNR and SSIM values were noted to be higher for conservative smoothing method followed by adaptive smoothing method as in Fig. 11 and 12.

Results clearly indicated that the conservative smoothing technique is best method among different image smoothing techniques to reduce the blur in an image. Main reason behind the better performance of adaptive median filtering is due to its ability to distinguish between noisy pixel and noise free pixel. This method is superior to other filters like mean and median filters in terms of its higher capability to preserve the detailed information in an image. This filtering technique also uses both minimum and maximum filtering concept to enhance both dark and light regions in an image. It could be noted from the sample output images of image smoothing methods that conservative smoothing filter technique has less distortion in an image, preserves detailed information and produces a better enhanced image output than other existing neighborhood processing methods.

Fig. 10. a) Original image, b) low level distortion image, Comparison of different smoothing techniques applied over (b), c) Mean Filter, d) Gaussian Filter, e) Anisotropic Diffusion, f) Conservative Smoothing, g) Median Filter, h)Adaptive Median Filter and i) Alpha trim mean filter.

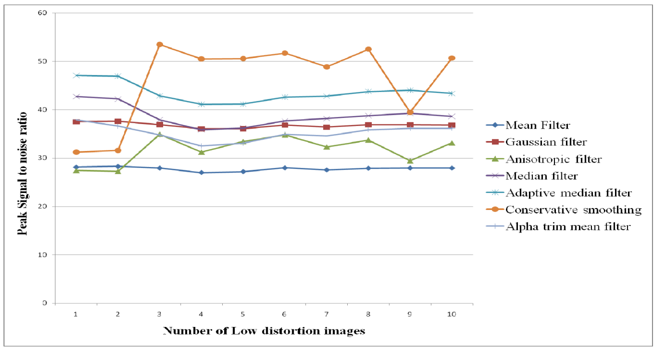

Fig. 11. Distribution pattern of Peak Signal to Noise Ratio values of image smoothing techniques.

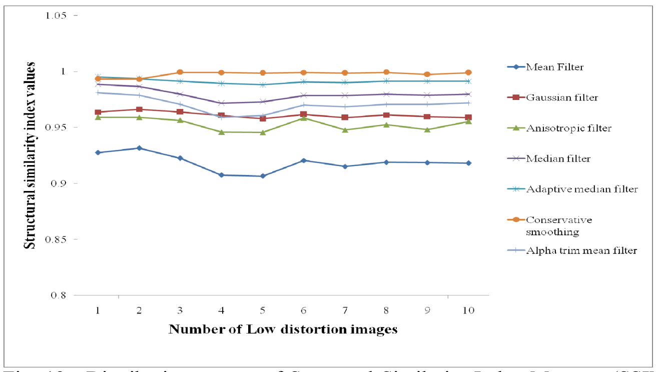

Fig. 12. Distribution pattern of Structural Similarity Index Measure (SSIM) values of image smoothing techniques

IV. Conclusion

Reducing the blurring effect in real time images is one of the challenging tasks. This paper reviewed various image smoothing techniques existing in literature. These image smoothing methods (mean filter, Gaussian filter, anisotropic diffusion, median filter, adaptive median filter, conservative smoothing and alpha trim mean filter) were applied over the images taken from CSIQ dataset. Performance of all methods was evaluated using Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM) criterion. It was noted that conservative smoothing technique of neighborhood processing method was performing better to reduce the blur effect. Hence it could be concluded that conservative smoothing would be suitable to enhance the image quality when it distorted by blur effect.

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