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Original Article

Analyzing the Performance of Image Denoising Techniques

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Abstract: With the increasing use of digital images, there is a growing demand for finer-tuned images that will improve the quality of what is being captured. Images captured by modern cameras are noisier, which reduces their quality. It is therefore imperative to reduce the amount of noise in these images, as well as the sharpness of the edges, corners, and other details of the image without reducing the image quality. Image noise is one of the main concerns on digital cameras. It has been found that there are a variety of techniques that can be used to reduce noise in images, each of which has different advantages and disadvantages. However, there is still a challenge and concern associated with image denoising since, when noise is removed from an image, the image is likely to appear blurred. The purpose of this paper is to discuss the characteristics of different types of noise in an image, as well as some of the different types of denoising techniques for the right way capture . The objective of this paper is to introduce various denoising techniques that can remove noise from images while maintaining a high level of image quality. Our study also utilized bilateral and nonlocal means filtering techniques, as well as total variability denoising to demonstrate the denoising in a noisy image. The numerical data in pixels in an image is typically changed by digital image filters (convolution kernels). Filters can cause artifacts in an image if they are not used carefully, leading to a misinterpretation of the data. We have ethically applied the filtering techniques in our experiment.

Key words: Image denoising, transform domain filtering, wavelet-based thresholding, bilateral filters and non-local means filters, total variation denoising, spatial filtering and ethical issue.

Introduction: Images are multidimensional arrays of numbers ranging from 0 to 255. An image consists of x (horizontal) and y (vertical) coordinates, which are commonly referred to as pixels. There are various types of images, like binary, color and greyscale images [1]. A variety of environmental transmission channels distortion and damage of material as a result of noise during compression, acquisition, and and a variety of tasks may result in image and a variety of tasks may result in image transmission [2]. The process of denoising plays

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an important role in the processing of images because noise may interfere with post-processing tasks such as image analysis and video tracking. Noise can therefore be attributed to errors in translation and compression[3].An image's noise characteristics can be influenced by several factors, including the type of sensor, the temperature, the pixel size, and the exposure time [4].

As an example of the types of noises that can be generated, one example is dark current noise. At many sensor sites, electrons produce dark current noise. The exposure time is closely related to the temperature of the sensor [4.]. It continues to be difficult for researchers to denoise images due to the fact that, whenever noise is removed from an image, the associated image becomes blurry. Accordingly, different algorithms are employed to remove noise from an image based on its model. Additionally, the noise level is also channel-dependent. In most cases, green channels tend to be the least noisy and blue channels tend to be the noisiest. This indicates that noise is not white in general. Digital images produce both high and low frequencies of noises [1]. Because it is difficult to distinguish low-frequency noise from real signals, removing high-frequency elements is also a challenge. As a rule of thumb, naturally occurring images are additive in nature, which can be modelled as Gaussian noise [2]. Speckle noise can also be observed in ultrasound images [5]and Rician noise can be observed in MRI images [6].

The denoising process is thus often a first and necessary step to take before analyzing image data. To compensate for any losses in data integrity, it is necessary to apply a denoising technique as efficiently as possible [7] As a result of denoisingas much of the important information about the image as possible is preserved, while the noise is removed.

Chang C.C. et.al in 2008 suggested in their research, to remove noise from the image, a new image-denoising filter based on the standard mean filter and a threshold is used, and the value of the original pixel, changed with the near value[8]. Median filters then used for impulse noise, and wavelet threshold methods are used for the find the corrupted pixels by Gaussian noise [9] . Jiang J.and Shen J.(2010) suggested to use the effective adaptive medium filter to remove the salt and pepper noise from the image [10].

There have been a number of methods developed over the years for denoising images; wavelet thresholding has been one of the most popular [10]. As, as the image information is concentrated in just a few large coefficients, wavelet thresholding is used to decompose the signal into its approximation (low-frequency) and detail (high-frequency) sub bands. It is the selection of the threshold that is critical to wavelet thresholding. There have been a number of threshold selection strategies proposed over the past few decades, for example, VisuShrink [11], SureShrink [12], and BayesShrink [13].

The bilateral filter has recently become a popular denosing method. The term "bilateral filter" was invented by Tomsi C in 1998[14], however others have developed variants such as the SUSAN filter [15], the neighborhood filter [16] , and the sigma filter [17] . Depending on spatial distance and intensity distance, a weighted sum of pixels in a local neighborhood is calculated for the bilateral filter. This method preserves edges while minimizing noise.

A denoising technique for removing noises from the image, which was proposed by [18] Ratna Babu et al removes salt and pepper noises. In addition, after removing the noise, it also preserves the original details of the image. In this research paper, the authors suggested that in the wavelet sub band domain for remove a noise from the image, an adaptive method is used. This approach is based on the threshold estimation for every sub band and considered Generalized Gaussian distribution for Each Sub Bend [19].

We have organized our paper as follows- In section 1 we discuss the concern of image noise in the introduction. In section 2 we discuss various techniques of image noising and denoising. Section 3 covers various quality metrics for performance evaluation criteria. In the next section we show our experiments and results, ethical issue in

image capture in right way and finally conclude the paper.

2. Image Noise and Denoising

2.1 Image Noise: Noise is generally introduced into images during transmission, acquisition, coding or processing. There are two types of noise models: additive noise and multiplicative noise. If the image c_n(x,y) represents a corrupted noisy image, whereaso_n(x,y) represents the original image, and n_n(x,y) represents the noisy image then-

$$c_{n(x,y)} = o_{n(x,y)} + n_{n(x,y)} \dots\dots\dots\dots\dots\dots\dots (1)$$

$$c_{n(x,y)} = o_{n(x,y)} * n_{n(x,y)} \dots\dots\dots\dots\dots\dots\dots (2)$$

Image noise can be classified into four types-, Gaussian noise, impulse, poisson noise and speckle noise. Noise generated by amplifiers is also called Gaussian noise. As a statistical noise, it is characterized by a Probability Density Function (PDF) which is comparable to the Gaussian distribution.

In addition to spike noise, Impulse Noise also known as salt and pepper noise, or random noise. A variety of factors cause this type of noise, such as sudden and sharp changes of the image signal, faulty equipment, and a malfunctioning imaging device

Electromagnetic waves such as X-rays, visible light, and gamma rays exhibit Poisson Noise noise due to their statistical nature.
Inactive radar and artificial aperture radar (SAR) images suffer from granular noise known as Speckle Noise which exists inherently in an image.

2.2 Image Denoising: It involves retaining the details in an image and removing the noise as much as possible from it. It can be divided into two classes: transform domain and spatial domain techniques

2.2.1 spatial domain techniques: To overcome the problems associated with the removal of unwanted noise from digital images, filter methods have been used to maintain the original image [20, 21]. The use of nonlinear filters has many applications, mainly for removing certain types of unwanted noise from digital images. Filters that remove noise when used nonlinearly usually blur images and blur edges. The problem has been addressed by researchers through the development of various types of median (nonlinear) filters over the last decade. A median filter is the most popular nonlinear filter, followed by partial differential equations, nonlocal mean, and total variation. Linear filtering is a denoising technique in which image output results change linearly. The denoising results vary depending on the input image. Images are linearly affected by changes in their inputs. Inverse linear filters for denoising an image take a certain amount of processing time based on the input signals and the output signals. Mean linear filters are the most effective filters to remove Gaussian noise from digital medical images. Wieclawek and Pietka [22] presented a technique for denoising digital images using only a few steps. The mean filter first calculates the average or mean pixels values of neighbour pixels and then replaces them with every pixel of the digital image.

2.2.2 Transform Domain Techniques: Data-adaptive filters and non-data-adaptive transforms are the main categories. Wavelet, contourlet, and curvelet are generally considered to be transform domain techniques. Many components of the ICA (independent component analysis) transformations techniques are included in data adaptive transforms, such as factor analysis and projection detection. Partition problems of blind source type have mainly been solved using this method. Digital medical images benefit from the removal of Gaussian and non-Gaussian noise. A linear filter is the most effective method to remove noise between the Weiner filter and the discrete filter. Most of the time, mean square error is used to determine the extent to which noise should be removed. The wavelet transform method is utilised if this method does not yield satisfactory results, where the noise is mapped to the signal using the wavelet transform method.

3. Performance Evaluation Criteria: In order to assess performance, two quality metrics are used: Peak Signal to Noise Ratio, (Structural Similarity Index Measure), and Scaled Signal to Noise Ratio (SSIR), which both compare the estimated image to the original true image.

3.1 Peak Signal to Noise Ratio: As a standard and commonly used quantitative metric in analysing retrieved images, peak signal to noise ratio (PSNR) is determined by the mean square error (MSE). The Mean Square Error is calculated by squaring the Euclidean distance between two images. A larger PSNR value indicates better denoising, which is independent of visual structure and details. The following equation is used to calculate the PSNR between two images X and X* when the pixel intensities are between 0 and 1.

$$PSNR\ (X,\widehat{X}) = 20\ \log_{10}\left(\frac{1}{\|X-\hat{X}\|_2}\right) \text{----------(3)}$$

3.2 Structural Similarity Index: In the denoised image, the structural similarity index measurement (SSIM) shows edges and fine details preserved, indicating a visually similar image compared with a PSNR. The following equations illustrate the formulas for quality criteria.

$$SSIM\ (X,\widehat{X}) = \frac{(2\mu X\mu\widehat{X} + k_1 2)\,(2a_{x+\widehat{k_2^2}})}{(\mu_x^2\ \mu_x^2 + k_1^2)(\sigma_x^2\quad \sigma_x^2 + k_2^2)} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where μX and μXˆ are the mean values of the images, σ 2 X and σ 2 Xˆ are the variance of the images, σXXˆ is the covariance of two images and k1 and k2 are two constants.

Methodology: For our experiments we did exploratory research in 2021 at the Department of Computer Applications, Manav Rachna International Institute of Research and Studies, India. To analyse the effects of denoising techniques, we first created a noisy image by adding noise and then performed various denoising techniques on it. Flowchart of the same has been shown in Figure 1.

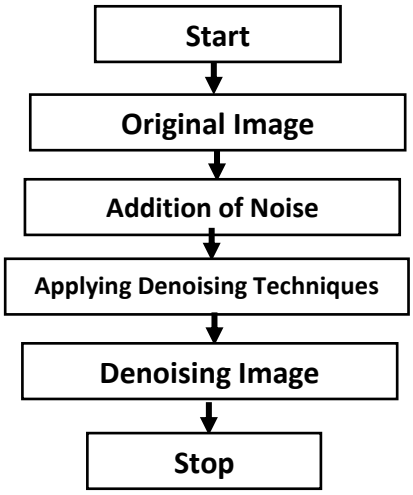

Figure 1: Flowchart of denoising approach

Results

Applying noise in an image: For adding noise into image by using random noise function, we obtained a noisy image as shown in figure 2.

More Noisy Image

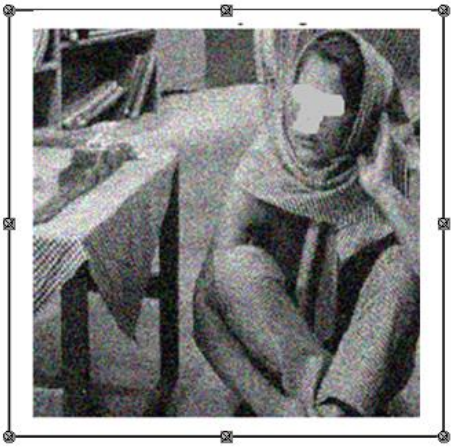

Figure 2: Test images (Noisy) Image: barbara (512 × 512).

To analyze the performance of denoising, we applied the following existing denoising methods-

1. Total Variation filter technique
2. Bilateral Filter denoising Technique
3. Non-local means denoising approach

Denoising of Image using total variation filter denoising: It is a method for reducing noise that preserves sharp edges in the underlying signal, referred to as Total Variation Denoising (TVD). Among the most common methods for suppressing image

noise is the total variation method. Nevertheless, this approach is easy to lose image details, and it depends on parameters such as the number of iterations to work properly. Denoising based on total variation can reduce noise in an image as well as preserve sharp edges in the underline signal. It is used for image restoration and filtering [23]. This process produces images that may be piecewise constant, but may contain less fine detail than the original non-degraded image. An image of the denoised image using this technique is shown in Figure 3.

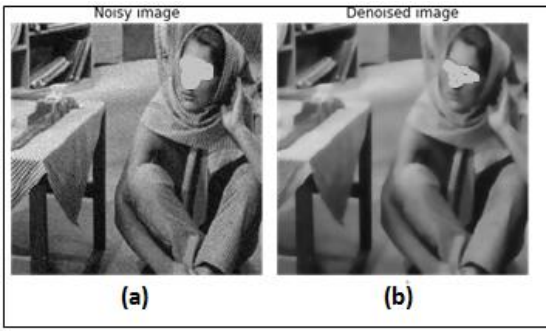

Figure 3: a) Noise Image b) Denoised Image *(Estimation of the noiseless Barbara (size 512 × 512) with noise standard deviation of 30. The PSNR is 27.26)*

Applying Bilateral Filter denoising Technique: An image denoising technique that has proven effective is the bilateral filter, a nonlinear filter that averages spatial data without smoothing edges. Selection of the filter parameters is an important issue when applying the bilateral filter, since they have a significant impact on the results. Bilateral filters have been used for a number of other things in addition to image denoising, including tone mapping, image enhancement, volumetric denoising, exposure correction, shape and detail enhancement from multiple images, and retinex. In spite of being conceived as a simple approach, recent studies have shown the filter is connected to some well-established methods. It is shown that the bilateral filter is the same as the Jacobi algorithm (diagonal normalized steepest descent) with a specific cost function. Denoised image by using bilateral filter technique shown in Figure 4.

Figure 4: Bilateral Filtering *(Estimation of the noiseless Barbara (size 512 × 512) with noise standard deviation of 30 . The PSNR is 26.91)*

Non-local means denoising approach: In addition to comparing the grey level in a single point, the (Non local) NL-means also compares the geometric configuration in the surrounding area. A robust comparison is therefore possible due to this fact. NL-means [24] can also be used to restore natural images due to their redundancy. A large number of flat zones lie inside the same object at the same time. Pixels in the filter using non-local means are assigned a mean, where they are weighted along with their similar pixels. With this type of filter, the post-processing clarity is much higher than with other types of algorithms, and information is not reduced as much . Figure 7 illustrates a denoised image obtained by using a non-local means denoising approach.

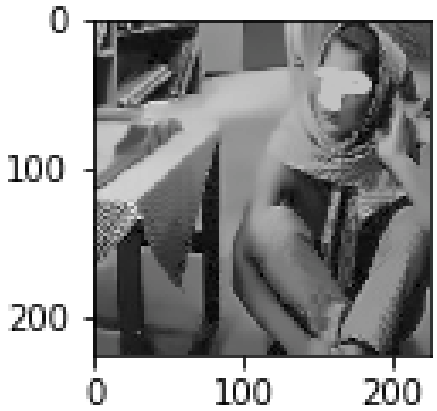

Figure 7: Denoised Image using Non-Local means approach *(Estimation of the noiseless Barbara (size 512 × 512) with noise standard deviation of 30. The PSNR is 27.94)*

Ethics of Using Image Right way: A digital image is an electronic resource that should be used responsibly and in accordance with ethical and copyright guidelines. There are usually instructions on how to use the images on most databases and websites. The usage guidelines should be read carefully and adhered to. It is important to keep in mind that usage guidelines can differ considerably, so paying attention to details and differences is crucial.

The use of images should not only adhere to legalities, but also follow ethical standards. Personal privacy and reputation should also be considered while representing people and situations accurately. Adding images to one's own content does not mean changing their meaning, content, or context.
The ethical use of images is governed by policies within many aid and social justice organizations. These can be helpful to gain a better understanding of how to represent each individual, community, and group in an ethical, fair, and appropriate manner.

Conclusion and Future Work: We discussed a survey of digital images in this paper. Because images are important for every region, the denoising process in images is an important pre-processing task. In image processing, various types of denoising approaches are used to remove noise from any image. The above comparative analysis shows various types of noise that affect the quality of the image. In this paper, we used various denoising approach: total variation filter, non-local mean filter and bilateral filter algorithm to remove noise and compared the performance of the methods. Comparison of the results is drawn along with three methods using established non local means, total variation filter and bilateral based filtering techniques. PSNR is used to evaluate the performance of the models. We have observed that the nonlocal means have the best PSNR performance out of the three models. Despite its non-invasive nature and low cost, ultrasound is a great imaging method for medical diagnosis due to its adaptability and the possibility of viewing images in real time. These images, however, contain too much noise to be used for medical analysis. In future we intend to extend our work using the ultrasound images and other types of medical images. Life science research has been greatly simplified and accelerated by the ubiquitous use of digital imaging. There are, however, serious ethical issues raised by the ease of manipulating digital images. Write one or two sentence

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Declaration: I hereby declare that comparative analysis of denoising techniques was done by me. I have thoroughly studied literature review and wrote the manuscript.

Conflict of interests: The authors declared that there is no conflict of interest in this study

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