A Comparative Study of Image Noise Reduction

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Abstract

There are several ways that noise can be introduced into an image, depending on how the image is created. Today, there are varieties of image noise reduction techniques. Several approaches have been introduced each has its own assumptions, advantages and disadvantages. In this paper, we study and compare three types of image noise reduction techniques: Inverse filter, Wiener filter and Lucy-Richardson filter. These filters are deconvolution types of filters. This paper attempts to undertake the study of three types of noise such as Salt and Pepper Noise (SPN), Gaussian Noise (GN) and Speckle Noise (SPKN). Different noise densities have been removed by using three types of filters as Inverse Filter (IF), Wiener Filter (WF) and Lucy-Richardson Filter (LF). These filters are applied to the car license plate image. The comparative study is conducted with the help of Mean Square Errors (MSE) and Peak-Signal to Noise Ratio (PSNR)..

1. Introduction

An image may be defined as a two dimensional function f(x, y), where x and y are spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x, y) is called the intensity or gray level of the image at that point [1]. Data sets collected by image sensor are generally contaminated by noise. The region of interest in the image can be degraded by the impact of imperfect instrument, the problem with data acquisition process and interfering natural phenomena. Therefore the original image may not be suitable for applying image processing techniques and analysis. Thus image enhancement technique is often necessary and should be taken as the first and foremost step before image is processed and analyzed.

Images are frequently corrupted by noise in the acquisition and transmission phases. Image restoration methods are used to improve the appearance of an image by application of a restoration process that uses a mathematical model for image degradation. Image noise reduction is the important problem of digital image processing preprocessing step. It can improve the accuracy or performance of other processing techniques that follow, such as image segmentation or recognition.

Image restoration methods can be considered as direct techniques when their results are produced in a simple one-step fashion. Equivalently, indirect techniques can be considered as those in which restoration results are obtained after a number of iterations. Known restoration techniques such as inverse filtering and Wiener Filtering can be considered as simple direct restoration techniques. The conventional Lucy-Richardson (LR) method is nonlinear and indirect techniques.

Inverse filter is a very basic restoration filter. This filter generally gives poor results and appropriate noiseless case of images. Wiener filter is commonly used in medical images for reduction speckle noise purposes. This filter works on frequency domain and requires statics of mean, variance and Signal to Noise Ratio (SNR). Lucy- Richardson filter is one of the most robust filters. It’s immune to almost everything. Since it is an iterative filter, it requires the no. of iterations. The organization of this paper is as follows: Section 2 describes the related work. Section 3 describes study type of noises, filters and comparative parameters. Section 4 presents the system design. Section 5 shows simulation result and Section 6 concludes this paper.

2. Related Work

Digital images are prone to a variety of types of noise. There are several ways that noise can be introduced into an image, depending on how the image is created.

Salem et al. [7] described remote sensing image noise removal studying three types of noise Salt & Pepper noise, Gaussian noise and Speckle noise and using five types of filters such as Mean, Standard Median, Adaptive Wiener, Gaussian filter and Adaptive Median filter. These filtering results are compared in terms of Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE). They approved Adaptive Wiener filter, Gaussian filter and Standard Median filter gave the best results in speckle and Salt & Pepper noise rather than the other two filters.

Salem Saleh et al. [6] compared deblurring model in noisy case and noiseless case of Wiener filter, Regularized filter and Lucy-Richardson filter. The Thangavel et al. [1] worked speckle noise reduction in ultrasound image based on Special filters: Max filter, Min filter, Harmonic Mean filter, Contra-Harmonic Mean filter, Geometric Mean filter and other filters. Compare these filtering results in terms of Mean Square Error (MSE), Root Mean Square Error (RMSE), Signal to Noise Ratio (SNR) and Peak Signal to Noise Ratio (PSNR).

Sudha et al [8] compared speckle noise reduction by using Frost filter, Wiener filter and other filters. This paper presents the performance analysis of various schemes for suppressing speckle noise in Ultrasound images in terms of the assessment parameters Peak-Signal-To-Noise-Ratio (PSNR) and Equivalent Number of Looks (ENL).

3. Types of Noises, Filters and Comparative factors

Noise is any undesired information that contaminates an image. Noise appears in image from various sources.

3.1 Types of Noise

There are three common types of noise which are described and compared in this paper.

3.1.1 Gaussian Noise (GN)

Gaussian noise is a type of white noise which is normally distributed over the image. Image corrupted by Gaussian noise is caused by random fluctuations in the signal during transmission [5]. The Gaussian noise can be modeled with a probability density function as:

$$p(z) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(z-\mu)^2/2\sigma^2} \qquad (1)$$

$p(z)$ is the Gaussian distribution noise in image μ and σ is the mean and standard deviation respectively.

3.1.2 Salt & Pepper Noise (SPN)

The Salt and Pepper type of noise is typically caused by malfunctioning of the pixel elements in the camera sensors, faulty memory locations, or timing errors in the digitization process. The probability density function is:

$$p(z) = \begin{cases} P_a & for\ z = a \\ P_b & for\ z = b \\ 0 & otherwise \end{cases} \qquad (2)$$

where: P_a , P_b is the Probabilities Density Function (PDF), $p(z)$ is distribution salt and pepper noise in image and a, b are the arrays size image. Salt & Pepper noise are also called impulsive noise.

3.1.3 Speckle Noise (SPKN)

In many cases the speckle noise degrades the fine details and edge definition, limits the contrast resolution. The multiplicative speckle is converted into additive noise after logarithm compression; the noise is spatially correlated, and has Rayleigh amplitude PDF:

$$p(z) = \begin{cases} \frac{2}{b} e^{-(z-a)^2/b} & for\ z \geq a \\ 0 & for\ z < a \end{cases} \qquad (3)$$

$p(z)$ is the speckle distribution of noise, a and b are the size of the image. The mean μ and variance δ of this density are given by:

$$\mu = a + \sqrt{\pi b/4} \qquad (4)$$

$$\delta^2 = \frac{b(4-\pi)}{4} \qquad (5)$$

3.2 Type of Filters

To recover the image from its noise there exits many filtering techniques which of them are: Inverse filter, Wiener filter and Lucy Richardson filter.

3.2.1 Inverse Filter

The simplest approach to restore image is direct inverse filtering. Inverse filter computes simply, the estimate image transform is the transform of the original image dividing the transform of the degradation function. Inverse filter is more appropriate in noiseless case of images and not appropriate in noisy case images. In this paper, inverse filter is passed by low pass filter and give smoother results than inverse filter only. Inverse filter computes simply, the estimate image transform, $\hat{F}(u,v)$ is the transform of the original image $G(u,v)$ dividing the transform of the degradation function $H(u,v)$.

$$\hat{F}(u,v) = \frac{G(u,v)}{H(u,v)} \qquad (6)$$

This technique is very fast because, once the restoration filter is specified, the solution is obtained just with one application of the filter. A problem with this method arises when the function $H(u,v)$ contains zeros, because then it is not possible to compute the division and thereby recover the frequency domain representation of the deconvolved image.

3.2.2 Wiener Filter

Wiener filters are a class of optimum linear filters which involve linear estimation of a desired signal sequence from another related sequence. A useful approach to this filter-optimization problem is to minimize the mean-square value of the error signal that is defined as the difference between some desired response and the actual filter output, the resulting solution is commonly known as the Wiener filter [2]. The Wiener filter is more robust in Speckle noise images and not so bad results in Salt & Pepper noise and Gaussian noise images. The objective of this filter is to find an estimate of the original image such that the mean square error between them is minimized. This error measured is given by:

$$e^2 = \left\{ \left(f - \hat{f} \right)^2 \right\} \tag{7}$$

e^2 = square of the error. f is the original image and $\hat{f}$ is the restored image. Wiener filter equation:

$$\hat{F}(u,v) = \frac{H^*(u,v)}{|H(u,v)|^2 + \frac{S_f(u,v)}{S_\eta(u,v)}} \quad G(u,v) \tag{8}$$

where, $\hat{F}(u,v)$ is the estimate image, $S_f(u,v), S_\eta(u,v)$ are respectively power spectrum of the original image and the additive noise, $H(u,v)$ and is the blurring filter. $H^*(u,v)$ is the complex conjugate of $H(u,v)$. $G(u,v)$ is the original image.

3.2.3 Lucy-Richardson Filter

A non-blind deconvolution algorithm developed in Richardson and Lucy, this doesn't require SNR estimation and this is iterative refinement procedural. The Lucy-Richardson algorithm is an iterative technique based on the Bayes' theorem or on a maximum-likelihood formulation under the assumption of Poisson distribution. This filter is one of the most robust filters. Its immune to almost everything. Since it is an iterative filter, it requires the no. of iterations. Increasing the iterations significantly increases the amount of time taken to restore an image [3]. The degradation process modeled by Lucy and Richardson does not take into account the additive noise term.

$$f_i = f_i \sum_k \left(\frac{h_{ki} g_k}{\sum_j h_{kj} f_j} \right) \tag{9}$$

$$\hat{f}_i^{(r+1)} = \hat{f}_i^{(r)} \sum_k \left(\frac{h_{ki} g_k}{\sum_j h_{kj} \hat{f}_j^{(r)}} \right) \tag{10}$$

$\hat{f}_i^{(r+1)}(x,y)$ is the estimation of output image. $h(u,v)$ and $g(u,v)$ is the degradation function and the input image.

3.3 Comparative Factors

The measurement of image enhancement is difficult to measure. There is no common algorithm for the enhancement of the image. The statistical measurement could be used to measure enhancement of the image. The Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR) are used to evaluate the enhancement performance [4].

3.3.1 Peak Signal to Noise Ratio (PSNR)

The PSNR is expressed in db is used instead of Signal to Noise Ratio (SNR) in the case of images or video and for impulse noise .The numerator value of 255 is corresponds to the maximum gray value, such as in a pixel. The highest values of PSNR give the better result of restored image. PSNR in terms of MSE is can be defined as:

$$PSNR = 20 log_{10} \frac{255}{\sqrt{MSE}} \; [db] \tag{11}$$

3.3.2 Mean Square Error (MSE)

$$MSE = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} \left[\hat{f}(x,y) - f(x,y) \right]^2 \tag{12}$$

For discrete image $f(x,y)$ for x=1, 2, 3,…m and y=1, 2, 3,…n. $f(x,y)$ is input image and $\hat{f}(x,y)$ is restored image. The mean square error measure is popular because it correlates reasonable with subjective visual quality test and it is mathematically tractable.

4. System design

This section presents the flow diagram of the system. Our comparative system consists of three processes: degradation, restoration and compare filtering results as shown in Figure 1.

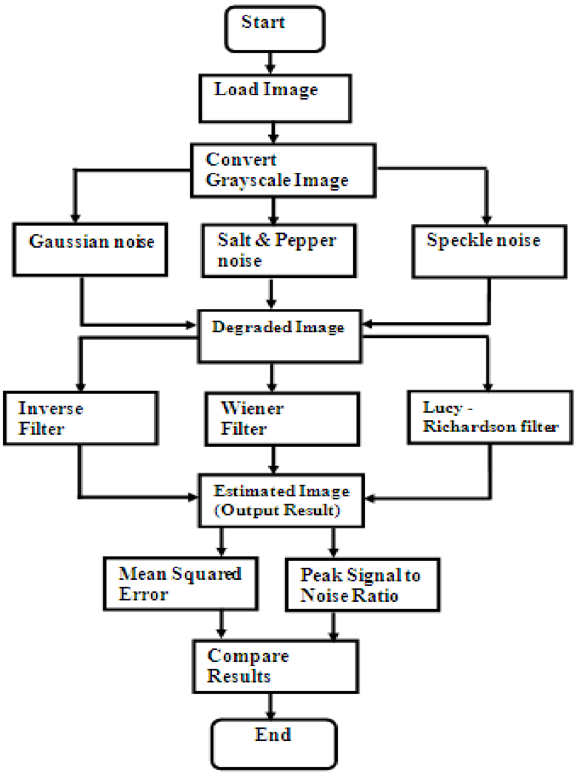

Figure1.System Flow Diagram

Image is loaded from the digital camera or from a folder that stores images for testing purposes. If the loaded image is RGB color image, it needs to be changed to the gray scale image.

Then, loaded image is added three types of noise: Gaussian noise, Salt & Pepper noise and speckle noise for tested purposes. This image is called degraded image.

The degraded image is restored using three types of filters: Inverse filter, Wiener filter and Lucy-Richardson filter.

The restored image is compared in terms of the assessment parameters Peak Signal to Noise-Ratio (PSNR) and Mean Square Error (MSE).

5. Experiments Verification

The filters were implemented using (MATLAB R2008b) and tested three types of noise: Gaussian Noise (GN), Salt & Pepper Noise (SPN) and Speckle Noise (SPKN) corrupted on the car license plate image illustrated in the Figure 2.

Fig.2 Car license Plate Image

Three types of filters are implemented in this image and the performance evaluation of the filtering operation is quantified by the PSNR (Peak Signal to Noise Ratio) and MSE (Mean Square Error).

(a)original (b)grayscale (c)noisly(SPN)

(d) Inverse (e) Wiener (f) Lucy

Fig.3 Image in SPN noise and filter results

Table 1: Computational Results of PSNR and MSE for Salt & Pepper noise (SPN)

Filtering methods	PSNR	MSE
Inverse filter	13.3637	0.0461
Wiener filter	18.6379	0.0137
Lucy filter	14.7008	0.0339

(a)original (b)grayscale (c) noisly(GN)

(d) Inverse (e) Wiener (f) Lucy

Fig.4 Image in GN noise and filter results

Table 2: Computational Results of PSNR and MSE for Gaussian noise (GN)

Filtering methods	PSNR	MSE
Inverse filter	13.3105	0.0467
Wiener filter	18.0489	0.0157
Lucy filter	13.9617	0.0402

(a)original (b)grayscal (c)nosily(SPKN)

(d) Inverse (e) Wiener (f) Lucy

Fig.5 Image in SPKN noise and filter results

Table 3: Computational Results of PSNR and MSE for Speckle noise (SPKN)

Filtering methods	PSNR	MSE
Inverse filter	13.4854	0.0448
Wiener filter	18.7732	0.0133
Lucy filter	15.0810	0.0310

5. Conclusion

In this paper, the comparative studies are explained and experiments are carried out for different filters. Wiener filter is the best filter for Speckle noise (SPKN) of license plate image see in figure (5). It is more robust than the other two filters. This filter also removed Gaussian noise (GN) and Salt & Pepper noise (SPN) with not so bad results. Inverse filter gives the worst results among three types of filter. Lucy filter is more robust than Inverse filter. In the figure (3) of Salt & Pepper (SPN) noise image, Lucy is given sharpen results than the other two filters. Wiener smoothed the SPN noise image so the result is not sharper than Lucy. The comparative study explains Wiener filter is the best for Speckle noise (SPKN) and Gaussian noise (GN).Lucy doesn't move three types of noise completely but this filter has sharpened results. Inverse filter doesn't achieve the best result for three types of noise.

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