Performance Analysis of Image Restoration Filters for Textual Images

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Abstract

In the modern era, images are one of the most important media used to store, transmit and analyze the information within it. True images often get degraded during the acquisition process due to environmental disturbances. Image Restoration techniques can be applied to restore such images to extract the information contained within the original data. Over the past years, several restoration techniques have been developed. In this paper, analysis of some of those techniques which are Wiener Filter, Richardson-Lucy Algorithm, Inverse Filter and Median Filter are performed for blur and noisy blur images. These methods have been utilized to restore the deteriorated images. Their performances are compared using factors like Power Signal to Noise Ratio (PSNR), Structural Similarity Index (SSI), and Mean Squared Error (MSE). These algorithms have been implemented on MATLAB(2020a) and the results show that Wiener Filter gives the best results for even blurred and noisy images.

Keywords: *Image Processing, Image Restoration, Blur, Wiener Filter, Richardson Lucy.*

I. INTRODUCTION

Image restoration is one of the most important approaches in digital image processing. It's used to recover the original image from a noisy one caused by environmental influences such as motion blur and camera misfocus. Image blur can be caused by a slow camera speed in comparison to the targeted object in motion. Due to transmission effects or low light environments during the image capture, certain noises such as Gaussian and Poisson noise appear in the images. In a nutshell, Image Restoration is an inverse process that is utilized to restore the distorted image back to its original form. This technique is valuable in a different field like medical and astronomical imaging, filmography, forensics science, law enforcement etc. Modelling the distortion and performing the inverse technique, to recover the original image are the main components of Image Restoration. These techniques are available in both the spatial and frequency domains.

II. LITERATURE SURVEY

Image pre-processing, enhancement, segmentation, restoration and other techniques have been used in the digital image processing concepts. These techniques are widely used for secure transmission of data [1]. In recent times, image processing techniques are utilized in every aspect and everywhere. Image pre-processing is one of the most engaging territories of the image processing concept [2]. Image Restoration plays a significant role among these processing techniques. It has been used in various application and in different fields such as remote sensing, medical image restoration, forensic science and so on. The restored images can further be used for different analysis purposes including medical analysis for diseases. Medical images can be taken by methods like Gamma Imaging, Radio Wave Imaging and X-ray Imaging [6]. The analysis of these captured images is done by segmenting the image and then further extracting the features in it to match the required criteria [4]. An image may contain a variety of noises and interferences, including Impulse, Gaussian, and Multiplicative noise. Due to the camera focus or misfocus by able lens, wide lens, long exposure times degradation, wind speed and other factors, many types of blurs like atmospheric, gaussian, motion and uniform blur may be seen in images. Haze or fog can also cause visual degradation due to atmospheric effects. [5].

To eliminate the image noise and blurs, many methods have evolved over the times such as wiener filter, harmonic mean filters, median filter, inverse filter, maximum like hood (MI) and max filter.

Among the works cited, Stephen focused on user-specified and available data of overlaying images specifically for processes in spatial domain. The technique is processed by Michael to eliminate blur in image for projector and out of focus layer [19]. Yu.et.al. suggested an algorithm for the images which are deteriorated by Gaussian and impulse noise [22]. On the basis of Neural Network techniques, image imprinting could be utilized for the digital image restoration. Adaptive KNN and deblurring CNN methods have been used to solve the inverse problem in the images.

Iterative methods can be used for the linear inverse issue in the denoising of the images. Among all the other filters, to remove the blur in the edge of an image, adaptive mean filters are used. Also, Median filter and Arithmetic mean filters are used in removing the blurs but they are complex and they consume more area and time.

In the real time scenario, due to environmental disturbance, de-focused image capturing and so on, different kinds of noises could be found. But when considering the real time noises, the type of noise which can be found in the surrounding is Blur. From number plate monitoring at traffic signals to motion pictures, blur noise is dominant in the real time scenarios. Real time images can also be analyzed by the FPGA implementations of the required filters. It is also done by initially acquiring the image, processing them, obtaining the image matrix and then followed by implementing the filter algorithm. Then, the restore matrix is converted back as the desired restored image [3]. Filters like Median Filter, Inverse Filter, Richardson-Lucy Algorithm and Wiener Filter are studied and modeled with noiseless blur and noisy blur images, to determine the best among them.

III. IMAGE RESTORATION

A. Introduction

Image Analysis could be used for a variety of image restoration application such as restoration of digital media, law enforcement, astronomical and medical imaging. However, distortion during capturing and recording degrades the image and might lead to loss in data. The degradation could be caused by noise in the image as a result of blurred images or noise detectors. These are the result of relative motion of the object and camera, random atmospheric disturbances and misfocus of camera during the capturing of an image. As a result, image restoration focuses on modelling the blurring and noise functions before deblurring and de-noising the image using an inverse model. In this work, filters like Median Filter, Inverse Filter, Richardson-Lucy Algorithm and Wiener Filter are studied and modeled with noiseless blur and noisy blur images, to determine the best among them for the Blur noise models.

B. Image Degradation Model

An Image can be described as a two-dimensional function I given as

$$I = f(x, y) \quad (1)$$

where I is the original image, x and y are considered as spatial co-ordinates. Amplitude of the function f at any point with coordinates (x, y) is called intensity I of that particular image I. When finite and discrete spatial coordinates and amplitude values are present in an image, then it is referred to as digital image. If f(x, y) is the original image, is a degradation function and η(x, y) is the additive noise then the degraded image g(x, y) can be described as follows:

$$g(x, y) = f(x, y)*h(x, y) + \eta(x, y) \quad (2)$$

where the symbol * indicates the convolution operation between the degradation function and the original image. Because, multiplication in the frequency domain equals to the convolution in spatial domain, the appropriate frequency domain representation is given as:

$$G(u, v) = F(u, v)H(u, v) + N(u, v) \quad (3)$$

where the terms mentioned in block letters are the Fourier transforms of the corresponding terms in equation.

Linear, position invariant processes can approximate various types of degradations. The term "image deconvolution" is utilized to describe linear image restoration because degradations are modelled as the outcome of convolution, and restoration entails finding filters which reverse the process.

C. PSF: Point Spread Function

The position invariant function h(x, y), which gets convolved with the original image to give the degraded image is referred to as the Point Spread Function(PSF).

a. Motion Blur

The smearing of moving objects captured on a camera in a snapshot or a succession of frames, such as a film or animation is referred to as Motion Blur. It occurs when the image which is being captured changes throughout the recording as a result of abrupt movement or long exposure.

b. Camera Defocus

Camera defocus blur is the lack of sharpness in an image caused by integrating light across a non-zero area aperture, in which the source of light is away from the image focal plane. The degree of blur apparent in any image is determined by the object and focal depth as well as lens aperture, and the camera pixel size.

D. Noise Models

The statistical behavior of the intensity values which might be regarded as random variables, and are described by a probability density function (PDF) are the basis for the noise's spatial component. Among the typically seen noise models, few of them are as follows:

1) Gaussian Noise Model: Natural causes of Gaussian noise include atom thermal vibrations and the discontinuous character of heated object radiation. It frequently causes the digital images to lose their grey values. [11]. Hence, Gaussian noise model essentially tries to normalize the histogram with respect to the gray values. Since it is usually seen in

amplifiers and detectors, it is also called as electronic noise.

2) White Noise: Noise power is used to identify noise. White Noise has a constant power spectrum. The power spectral density function is similar to the noise power. The total noise power range possible in white noise in the frequency domain is $-\infty$ to $+\infty$ implying that , the noise-power in white noise is essentially infinite. It is absolutely accurate as the sun's radiation contains all of the frequency components.

Co-relation is impossible in white noise, as all pixel values are distinct from their neighboring pixels. That is why there is np auto-correlation. As a result of white noise, the image pixel values are generally disrupted positively.

3) Impulse Noise: Impulse noise are short duration noise which are randomly distributed over the complete image. Because the original data values are dropped, it is also referred to as data drop noise. Another name for this phenomenon is the "salt and pepper noise". However, rather than the entire image being distorted by the salt and pepper noise, only a few pixel values are altered. Despite the fact that certain neighbors may not alter in the noisy image, this noise could be seen in data transmission. The image pixel values are replaced by the corrupted pixel values. If the number of transmitted bits are 8, then the minimum and maximum values for the replaced bits are 255 and 0 respectively.

E. Median Filter

The Median Filter is a non-linear filtering method for removing noise from the images. This technique is often utilized where there is a need for preserving the edges from the blur. Particularly, they are used in restoring the images which are affected from the 'salt and pepper' noise. Pixel value inside a window, is replaced by the neighborhood's median value. It works by moving through the image pixel by pixel and replacing the median values. The pattern of neighborhood pixels is called window. By sorting all pixel values inside the window into ascending and descending order, and further by replacing the pixel in question with the center pixel value, the median is calculated.

F. Inverse Filter

The primary goal of image restoration is restoring an image from the deteriorated image. The more information we collect about the deterioration process, the more likely are the chances to recover the original image. This is called as a priori knowledge. There are numerous ways for restoring an image, some of which use frequency domain principles while others seek to simulate the degradation and apply the inverse process. The modelling approach necessitates selecting a criterion that will get the best result.

If there is a prior knowledge regarding the modelling of the blurring function which caused the corruption in an image, then the simplest method to recover the image in question is by inverse filtering. Let f be an original image, h be the blurring kernel, and g be the blurred image. Inverse filtering works by recovering the original image from the blur image. The DFT of the blurred image can be calculated using the convolution theorem as the product of the DFT of the original image and the DFT of the blurring kernel. It is thus possible to retrieve the original image by dividing the DFT of the blur image by the DFT of the kernel. Then the inverse frequency filter, R(u), which can be written as 1/H(u) could be applied. In this case, the system is presumed to be noiseless. Let

$$g(x, y) = f(x, y)h(x, y) \quad (5)$$

where the symbol * indicates the convolution operation between the degradation function and the original image. Because multiplication in frequency domain equals convolution in spatial domain, the appropriate frequency domain representation is given as,

$$G(u, v) = F(u, v)H(u, v) \quad (6)$$

where the terms in capital are the Fourier transforms of the corresponding terms in equation.

If there is any additional noise present after applying the motion blurring effect then the following formula below can be used to recreate the original image:

$$F'(u,v) = F(u,v) + \frac{N(u,v)}{H(u,v)} \quad (7)$$

It is impossible to retrieve F(u, v) accurately since, the function of N(u, v) is random and Fourier transform is usually unfamiliar. The effect of noise is only visible for the frequencies with small magnitude of H(u, v). In practice, H(u, v) decreases considerably more quickly than N(u, v), and therefore the impact of noise may overwhelm the entire restoration outcome.

G. Wiener Filter

Inverse filter can be used to repair the corrupted image in such cases where the degradation function responsible for the blurring is known. It is nevertheless very susceptible to additive noise. By simultaneously reducing additive noise and inverting blurring, it provides a great tradeoff between noise smoothing and inverse filtering.

It is effective in terms of mean square error. In the inverse filtering process, it aims to reduce the overall mean square error [12] It is possible to think of it as a linear estimation of the original image. Because of the orthogonality principle, in the Fourier domain, this filter can be stated as:

$$L(u,v) = \frac{H^*(u,v).S_f(u,v)}{|H(u,v)|^2 S_f(u,v) + S_n(u,v)} \quad (8)$$

$$L(u,v) = \frac{H^*(u,v)}{|H(u,v)|^2 + \frac{S_n(u,v)}{S_f(u,v)}} \quad (9)$$

$$L(u,v) = \frac{H^*(u,v)}{|H(u,v)|^2 + K} \quad (10)$$

where,

$S_n(u, v)$ = Power Spectrum of noise image

$S_f(u, v)$ = Power Spectrum of original image

Both the noise and image are random processes. If only the random processes are stationary Gaussian, can the Wiener filter produce the most favorable estimate. For real images, both the image and noise are considered as random process.

H. Richardson-Lucy Algorithm

A particular solution for the restoration of an original image from a corrupted one mainly depends on the form of degradation that is seen in the image. One of the main reasons for the popularity of this algorithm is it’s ability to produce good quality restored images even in the presence of additive noise. It generates the output through iteration method. It works in such a way that the (n+1)th estimate of the restored image depend on the nth iteration multiplied by the correction image. The result from each iteration is used to make a prior to the following iteration. The more the number of iterations, the finer will be the result.

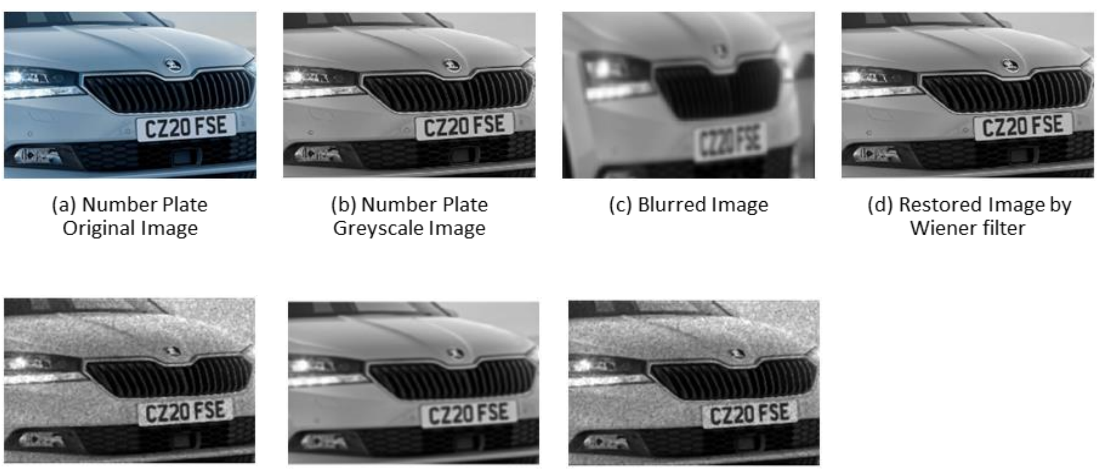
IV. SIMULATIONS AND RESULTS

The simulations were carried out using MATLAB. Two sets of images were taken and the results for each filter with. the blur model and with the noise model were simulated. The images considered for the restoration techniques analysis and their respective performance matrices comparisons are as follows:

Figure 1: Restoration stages for Lena

(a) Lena Original Image
(b) Lena Greyscale Image
(c) Blurred Image
(d) Restored Image by Wiener filter
(e) Restored Image by Median filter
(f) Restored Image by RL Algorithm
(g) Restored Image by Inverse Filter

Figure 2: Restoration stages for Number-Plate Image

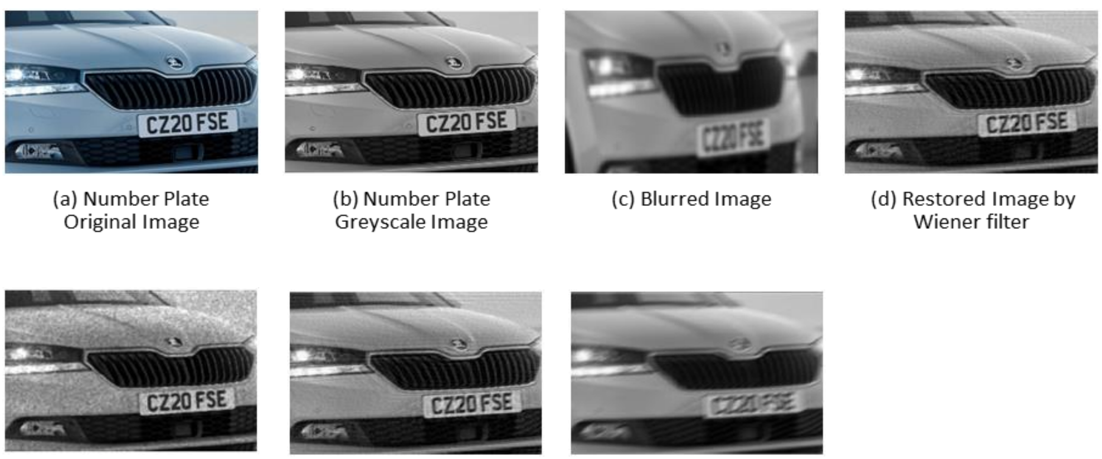


(a) Number Plate Original Image
(b) Number Plate Greyscale Image
(c) Blurred Image
(d) Restored Image by Wiener filter
(e) Restored Image by Median filter
(f) Restored Image by RL Algorithm
(f) Restored Image by Inverse filter

Figure 3: Restoration stages for Lena with Gaussian Noise

(a) Lena Original Image
(b) Lena Greyscale Image
(c) Blurred Image
(d) Restored Image by Wiener filter
(e) Restored Image by Median filter
(f) Restored Image by RL Algorithm
(g) Restored Image by Inverse Filter

Figure 4: Restoration stages for Number-Plate Image with Gaussian Noise



(a) Number Plate Original Image
(b) Number Plate Greyscale Image
(c) Blurred Image
(d) Restored Image by Wiener filter
(e) Restored Image by Median filter
(f) Restored Image by RL Algorithm
(f) Restored Image by Inverse filter

Figure 5: Restoration stages for Sign-Board Image

(a) Sign Board Original Image (b) Sign Board Greyscale Image (c) Blurred Image (d) Restored Image by Wiener filter

(e) Restored Image by Median filter (f) Restored Image by RL Algorithm (g) Restored Image by Inverse Filter

Figure 6: Restoration stages for Sign-Board Image with Gaussian Noise

(a) Sign Board Original Image (b) Sign Board Greyscale Image (c) Blurred Image (d) Restored Image by Wiener filter

(e) Restored Image by Median filter (f) Restored Image by RL Algorithm (g) Restored Image by Inverse Filter

In the proposed work, Wiener, Inverse, Median Filter and Lucy-Richardson filters were utilized on blur and non-blur images. PSNR, SSIM and MSE are the performance parameters which are utilized to compare these filters.

The comparison of the Performance Matrices are as follows:

Table I: Comparison of PSNR values

Image	Median	RL	Inverse	Wiener
Lena	23.7	29.78	30.11	31.7
Number Plate	22.1	25.6	27.12	28.3
Sign Board	24.2	24.9	26.9	27.3

Table II: Comparison of MSE values

Image	Median	RL	Inverse	Wiener
Lena	0.0029	0.0032	0.0025	0.0015
Number Plate	0.0075	0.0082	0.0062	0.0057
Sign Board	0.0028	0.0042	0.038	0.031

Table III: Comparison of SSIM values

Image	Median	RL	Inverse	Wiener
Lena	0.681	0.739	0.9322	0.9725
Number Plate	0.5128	0.6458	0.8856	0.9125
Sign Board	0.5012	0.5621	0.7832	0.8256

Table IV: Comparison of PSNR values for noise blur

Image	Median	RL	Inverse	Wiener
Lena	22.7	24.48	26.13	28.2
Number Plate	20.07	22.8	23.35	25.4
Sign Board	22.6	23.2	23.91	25.2

Table V: Comparison of MSE values for noise blur

Image	Median	RL	Inverse	Wiener
Lena	0.0020	0.0017	0.0015	0.0012
Number Plate	0.0057	0.0045	0.0053	0.0061
Sign Board	0.0052	0.0043	0.0049	0.0042

Table VI: Comparison of SSIM values for noise blur

Image	Median	RL	Inverse	Wiener
Lena	0.423	0.533	0.521	0.785
Number Plate	0.321	0.425	0.577	0.699
Sign Board	0.363	0.392	0.529	0.652

V. SUMMARY AND CONCLUSIONS

Image Analysis is a significant part in the Image pre-processing proces. Image Restoration is one of the most crucial aspects in the Image Processing techniques because it removes the unwanted noise from the image that has been injected due to a variety of factors. Over the time, number of techniques have been evolved to restore a degraded image. In this work, Wiener, Median, Inverse filter and Lucy Richardson Algorithm were implemented and applied on two set of images for degradation models and additive noise. The aim of this work is focused on conducting a comparison study of the Image restoration approaches. Though each technique has its own approach to the problem and carry their own pros and cons.

It is observed from the work that the Wiener filter was the best technique for restoring the image with both blur and non-blur noise for all the measured parameters, like PSNR, SSIM, and MSE. It was observed that for images without additive noise, Inverse and Wiener filter provided similar results. With the addition of noise, it is Wiener filter which gives the better results. On the PSNR comparison front, all the filters apart from Median have very small difference in the output margin. It was also observed that, if the iterations for the Lucy-Richardson algorithms are increased, then the restoration results are better from the current results. Overall, Wiener filter gives better results in comparison to other algorithms.

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