A Comprehensive Review on Image Restoration Techniques

Biswa Ranjan Mohapatra, Ansuman Mishra, Sarat Kumar Rout
Department of CSE, BIET, Bhadrak
Odisha

Abstract- Image restoration is an art to improve the quality of image via estimating the amount of noises and blur involved in the image. With the passage of time, image gets degraded due to different atmospheric and environmental conditions, so it is required to restore the original image using different image processing algorithms. There is a wide spread application of image restoration in today's world. Application area varies from restoration of old images in museum and radar based image acquisition and restoration. This paper gives a review of different image restoration techniques used.

Keywords- Blur, image restoration, image acquisition

1. INTRODUCTION

Image restoration is based on the attempt to improve the quality of an image through knowledge of the physical process which led to its formation. The purpose of image restoration is to "compensate for" or "undo" defects which degrade an image. Degradation comes in many forms such as motion blur, noise, and camera mis-focus. In cases like motion blur, it is possible to come up with a very good estimate of the actual blurring function and "undo" the blur to restore the original image. In cases where the image is corrupted by noise, the best we may hope to do is to compensate for the degradation it caused. Image restoration differs from image enhancement in that the latter is concerned more with accentuation or extraction of image features rather than restoration of degradations. Image restoration problems can be quantified precisely, whereas enhancement criteria are difficult to represent mathematically.

Image restoration started in 1950's. There are several application domain of image restoration like scientific exploration, legal investigations, film making and archivals, image and video decoding and consumer photography. The main area of application is image reconstruction in radio astronomy, radar imaging and tomography.

This paper discusses the importance of image restoration techniques and reviews different image restoration techniques available.

2. IMAGE RESTORATION

Image restoration uses a priori knowledge of the degradation. It models the degradation and applies inverse process. It formulates and evaluates the objective criteria of goodness. The distortion can be modelled as noise or a degradation function. To restore an image from a noise model, different filters like median filter, homomorphic filters are used. To get rid of periodic noises, butterworth lowpass filter, butterworth band reject filters and notch filters are used. To restore an image from linear degradation, inverse and pseudo inverse filtering, wiener filtering and blind de-convolution are used.

A simplified version for the image restoration process model is $y(i,j) = H\left[f(i,j)\right] + n(i,j)$ (1)

Where $y(i,j)$ is the degraded image, $f(i,j)$ is the original image, H an operator that represents the degradation process, $n(i,j)$ the external noise which is assumed to be image-independent.

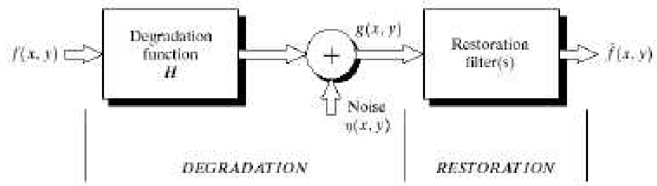


Figure 1: Image degradation and restoration techniques

Noise Models

In image processing there are different noise models available.

Gaussian Noise can be represented as

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

Rayeligh's noise can be represented as

$$p(z) = \frac{2}{b}(z-a)e^{-\frac{(z-\mu)^2}{b}} \qquad (3)$$

Salt and Pepper noise can be represented as

$$p(z) = P_a\delta(z-a) + P_b\delta(z-b) \qquad (4)$$

There are different kinds of blurs involved in images some of the blurs are discussed below.

Blur Models

Motion blur occurs when there is relative motion between the object and the camera during exposure. This can be in the form of a translation, a rotation, a sudden change of scale, or some combinations of these.

$$h(i) = \begin{cases} \frac{1}{L} & -\frac{L}{2} \le \frac{L}{2} \\ 0 & else \end{cases} \qquad (5)$$

Atmospheric turbulence occurs due to random variations in the reflective index of the medium between the object and the imaging system and it occurs in the imaging of astronomical objects.

$$h(i,j) = K\exp\left(-\frac{i^2+j^2}{2\sigma^2}\right) \qquad (6)$$

When a camera images a 3-D scene onto a 2-D imaging plane, some parts of the scene are in focus while other parts are not. If the aperture of the camera is circular, the image of any point source is a small disk, known as the circle of confusion (COC). The degree of defocus (diameter of the COC) depends on the focal length and the aperture number of the lens, and the distance between camera and object. An accurate model not only describes the diameter of the COC, but also the intensity distribution within the COC. However, if the degree of defocusing is large relative to the wavelengths considered, a geometrical approach can be followed resulting in a uniform intensity distribution within the COC. Uniform out of focus blur is defined by

$$h(i,j) = \begin{cases} \dfrac{1}{\pi R} & \sqrt{i^2+j^2} \le R \\ 0 & else \end{cases} \qquad (7)$$

Uniform 2-D blur is defined by

$$h(i) = \begin{cases} \dfrac{1}{L^2} & -\dfrac{L}{2} \le i, j \le \dfrac{L}{2} \\ 0 & else \end{cases} \qquad (8)$$

Performance Indices

Blurred Signal-to-Noise Ratio (BSNR) is a metric that describes the degradation model.

$$BSNR = 10\log_{10}\left[\frac{\dfrac{1}{MN}\sum_i\sum_j\left[h(i,j)-\tilde{h}(i,j)\right]^2}{\sigma_n^2}\right] \qquad (9)$$

Here $h(i,j) = y(i,j) - n(i,j)$, $\tilde{h}(i,j) = E\left[h(i,j)\right]$ and σ_n^2 is variance of additive noise. Improvement in SNR (ISNR) validates the performance of the image restoration algorithm.

$$ISNR = 10\log_{10}\left[\frac{\sum_i\sum_j\left[f(i,j)-y(i,j)\right]^2}{\sum_i\sum_j\left[f(i,j)-\tilde{f}(i,j)\right]^2}\right] \qquad (10)$$

where $\tilde{f}(i,j)$ is the restored image.

Median Filter

Figure 2 shows an image, heavily corrupted by salt and pepper noise and 3x3 median filtered is used to remove the noise.

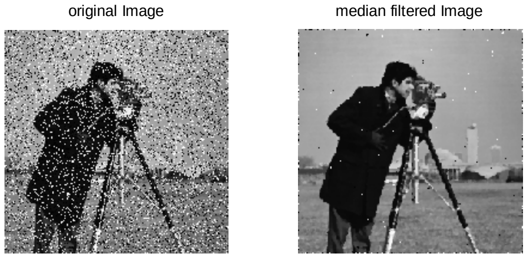


Figure 2: Noisy Image and Median filtered image

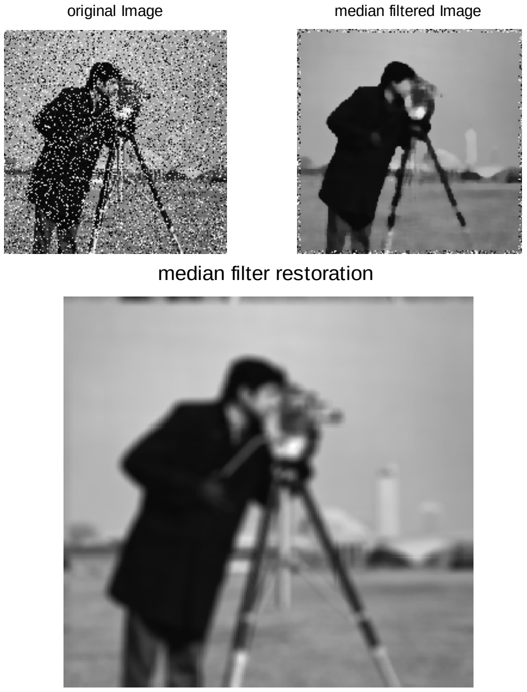


Figure 3: Image degradation and restoration techniques

Figure 3 show the same noisy image heavily corrupted by salt and pepper noise and median filter of window size (9x9) is used. The higher the window size of median filter there is a higher chance of image degradation.

Table 1: PSNR value (dB) for % of salt and pepper noise (Image: Cameraman, Filter: Median)

		10%	20%	50%	90%
1	MF (3X3)	33.7	27.28	14.12	6.54
2	MF (5X5)	31.44	30.67	12.88	7.29
3	MF (9X9)	29.47	28.99	16.54	8.09

To restore an image from linear degradation inverse filter, pseudo inverse filter, Weiner filter and blind de-convolution is used. These techniques are discussed below.

Inverse Filtering

Inverse filter can be expressed as $\tilde{H}(u,v)=\frac{1}{H(u,v)}$ and the recovered image can be expressed as $\tilde{F}(u,v)=G(u,v)\tilde{H}(u,v)$


Degraded Image
Restored Image

Figure 4: Image degradation and restoration using inverse filter

Pseudo Inverse Filter

Pseudo inverse filter can be expressed as

$$\tilde{H}(u,v)=\begin{cases}\frac{1}{H(u,v)} & |H(u,v)|\geq\varepsilon \\ 0 & |H(u,v)|<\varepsilon\end{cases} \quad (11)$$

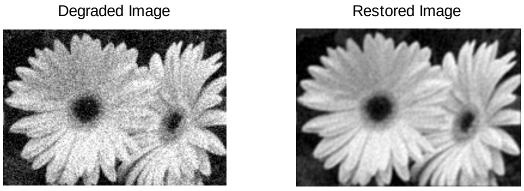
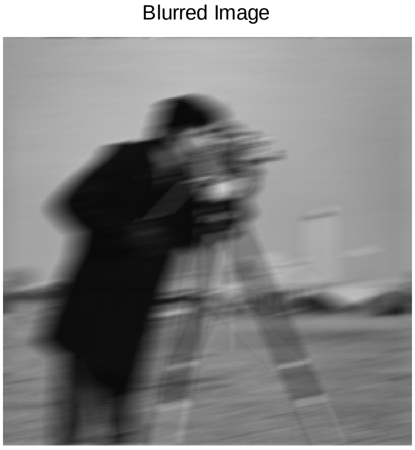

Degraded Image
Restored Image

Figure 5: Image degradation and restoration using pseudo inverse filter


Blurred Image


show noisy with degraded image


pseudo-inverse restoration

Figure 6: Image degradation and restoration using pseudo inverse filter

Weiner Filter

The main disadvantage of Weiner filter is that it can't handle noises. So minimum mean square error filtering (Weiner filter) is used which incorporates both the degradation function and statistical characteristics of noise in to image restoration process. In this method it is assumed that the noise and degradation function are uncorrelated. One of them has zero mean. The objective function of Weiner filter is as follows,

$$\min_{h_r(x,y)} E\left\| f(x,y)-\tilde{f}(x,y)\right\|^2 \equiv \min_{h_r(x,y)} C_{ee}(\omega_x,\omega_y) \quad (12)$$

$$H_r(\omega_x,\omega_y)=\frac{\tilde{H}(\omega_x,\omega_y)}{\left|H(\omega_x,\omega_y)\right|^2+\frac{C_{nn}(\omega_x,\omega_y)}{C_{ff}(\omega_x,\omega_y)}} \quad (13)$$

The main disadvantage of Weiner filter is that the power spectra of undergraded image and power spectra of noise must be known.

Restoration of Blurred, Noisy Image Using Estimated NSR

Restoration of Blurred, Quantized Image Using Computed NSR

wiener filter restoration

Figure 7: Image degradation and restoration using Weiner filter

Geometric Mean Filter

Geometric mean filter is the generalization form of Weiner filter. The mathematical expression of geometric mean filter is defined as

$$F(u,v)=\left[\frac{H(u,v)}{\left|H(u,v)\right|^{2}}\right]^{\alpha}\left[\frac{H(u,v)}{\left|H(u,v)\right|^{2}+\beta\left[\frac{S_n(u,v)}{S_f(u,v)}\right]}\right]^{1-\alpha}G(u,v) \tag{14}$$

Geometric Mean filter restoration

Figure 8: Image degradation and restoration using geometric mean filter restoration

Blind Deconvolution Algorithm

The Blind Deconvolution Algorithm can be used effectively when no information about the distortion (blurring and noise) is known. The algorithm restores the image and the point-spread function (PSF) simultaneously. The accelerated, damped Richardson-Lucy algorithm is used in each iteration. Additional optical system (e.g. camera) characteristics can be used as input parameters that could help to improve the quality of the image restoration. Blind deconvolution is the problem of recovering a sharp version of an input blurry image when the blur kernel is unknown. Mathematically $y = k \otimes x$

Where x is a visually plausible sharp image, and k is a non negative blur kernel, whose support is small compared to the image size.

Blurred Image

Figure 9: Image degradation and restoration using blind deconvolution algorithm

Richardson-Lucy Deconvolution Algorithm

The Richardson–Lucy deconvolution algorithm has become popular in the fields of astronomy and medical imaging. Initially it was derived from Bayes's theorem in the early 1970's by Richardson and Lucy.

Pixels in the observed image can be represented by

$$d_i = \sum_j p_{ij} u_j \tag{15}$$

$$u_j^{t+1} = u_j^t \sum_i \frac{d_i}{c_i} p_{ij} \tag{16}$$

$$u_j^{t+1} = u_j^t \left(\frac{d}{u^t \otimes p} \otimes \hat{p} \right) \tag{17}$$

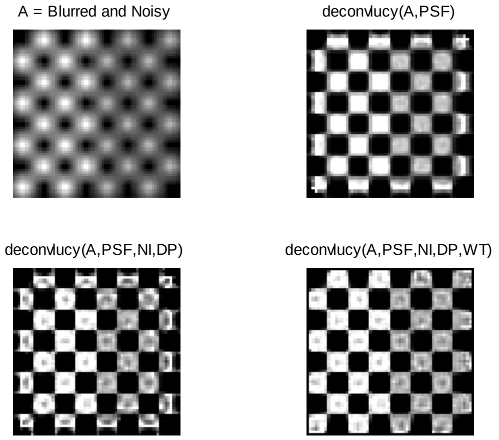


Figure 10: Image degradation and restoration using Richardson-Lucy blind deconvolution algorithm

3. CONCLUSIONS

This paper gives a review of different image restoration algorithms. Image restoration is an active research area and various researchers work to improve the efficiency of the different algorithms by developing more efficient algorithms. But primarily image restoration is done mostly using Weiner filter, Richardson-Lucy Blind Deconvolution algorithm, Inverse and Pseudo-inverse filter.

REFERENCES

1. D A Fish, A M Brinicombe, E R Pike, "Blind deconvolution by means of the Richardson-Lucy algorithm," J. Opt. Soc. Am. A., vol. 12, no. 1, Jan 1995, pp 58 – 65
2. D. Kundur and D. Hatzinakos, "Blind image deconvolution," IEEE Signal Processing Magazine, 1996.
3. C Khare, K K Nagawanshi, "Implementation and analysis of image restoration techniques," International Journal of Computer Trends and Technology, May 2011
4. H C Andrew, B R Hunt, "Digital image restoration," Prentice Hall
5. K. R. Castleman, "Digital Image Processing", International Edition, Prentice-Hall, Inc., 1996.
6. Neelamani R., Choi H., and Baraniuk R. G., "Forward: Fourier-wavelet regularized deconvolution for ill-conditioned systems", IEEE Trans. on Signal Processing, Vol. 52, No 2 (2003) 418-433.
7. C. Helstrom, "Image Restoration by the Method of Least Squares", J. Opt. Soc.Amer., 57(3): 297-303, March 1967.
8. Amandeep Kaur, Vinay Chopra, "A comparative study and analysis of image restoration techniques using different image formats," International Journal of Science and Emerging Technologies with latest trends, 2, 1, pp. 7-14, 2012
9. P. Campisi and K. Egiazarian, "Blind image deconvolution theory and applications , CRC Press,2006.
10. K. H. Yap and L. Guan, "A computational reinforced learning scheme to blind image deconvolution , " IEEE Transactions on Evolutionary Computation, vol. 6, no. 1, pp. 2-15, 2002.