An Improved Restoration Tool Based on Blind Image Deconvolution with Curvelet Transform

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***Abstract*—Image restoration deals with bringing back the degraded image to its original state i.e. it helps to restore the degraded image into more sharp and clear image. This research paper proposes a novel and improved restoration technique using blind image deconvolution and curvelet transform. A degraded image contains some unwanted things like noise and blur. The main goal of the restoration algorithm is to recover the image from the effect of noise and blur.**

***Keywords*—*Curvelet; Ridglet; Renormalization; Subband decomposition; Smooth Partitioning; BID.*

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I. INTRODUCTION

Image restoration is an emerging field of image processing in which the focus is on recovering an original image from a degraded image. The degraded image can be a result of a known degradation or unknown degradation. Hence image restoration can be defined as a process of recovering a sharp image from a degraded image which is blurred by a degradation function, commonly by a Point Spread Function (PSF). It is an objective area. 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 misfocus. 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 is to compensate for the degradation it caused [1][8][21].

A. Image Degradation /Restoration model

The complete process of image restoration is divided into two stages according to degradation/ restoration model. The first stage deals with degrading the quality of the image by adding blur and noise to an image and the second stage deals with removing noise and blur from the degraded image and recovering the original image. These two sub stages are named as degradation stage and restoration stage respectively.

In degradation stage, the image is blurred using degradation function and additive noise. In Restoration stage, the degraded image is reconstructed using restoration filters. In this process noise and blur factor is removed and we get an estimate of the original image as a result of restoration. The closer the estimated image is to the original image the more efficient is our restoration filter [18][19].

Mathematically, the equation for degradation / restoration model is represented in two different domains i.e. Spatial domain and Frequency domain.

In Spatial domain:

$g(x, y) = h(x, y) * f(x, y) + \eta(x, y)$ (1)

In Frequency domain:

$G(u, v) = H(u, v) F(u, v) + N(u, v)$ (2)

where $g(x, y)$ is degraded image obtained by adding noise $\eta(x, y)$ to image $f(x, y)$ after applying a degradation function $h(x, y)$. $G(u,v)$ is frequency domain equivalent to $g(x, y)$, $H(u, v)$ is degradation function in frequency domain. $N(u,v)$ is additive noise and $F(u, v)$ is original image in frequency domain. The degradation function which works in spatial domain is point spread function (PSF).

1) Blind Image Restoration: This Technique allows the reconstruction of original images from degraded images even when we have very little or no knowledge about PSF. Blind Image Deconvolution (BID) is an algorithm of this type. These techniques are more difficult to implement and are more complicated as compared to other category [13].

2) Non-Blind Restoration: This Technique helps in the reconstruction of original images from degraded images when we know that how image was degraded i.e. we have a knowledge about PSF. LRA i.e. Deconvolution using Lucy Richardson Algorithm is one among various non-blind techniques.
The objective of restoration is to obtain an estimate $\hat{f}(x,y)$ of the original image This estimate $\hat{f}(x, y)$ should be as close to f(x,y) as possible. The more we know about h and η , the more $\hat{f}(x,y)$ will be closer to f(x,y). F

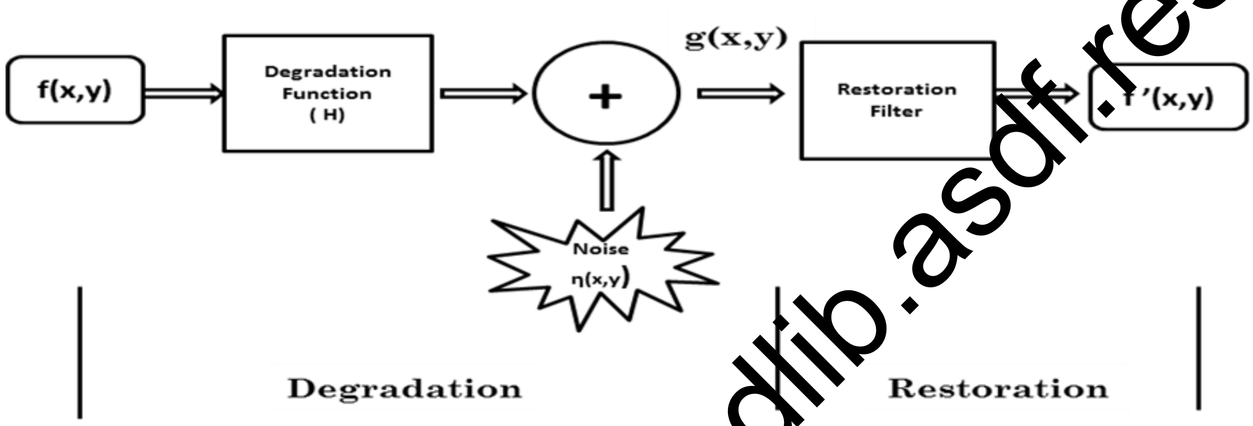

Fig. 1. Image Degradation/Restoration Model

B. Restoration techniques
There are numerous techniques and algorithms available for image restoration [11][12]. Each technique has its own features. Broadly, Image restoration techniques are classified into two categories which are shown in Fig. 2. Following is a brief introduction of both the image restoration techniques [16][18].

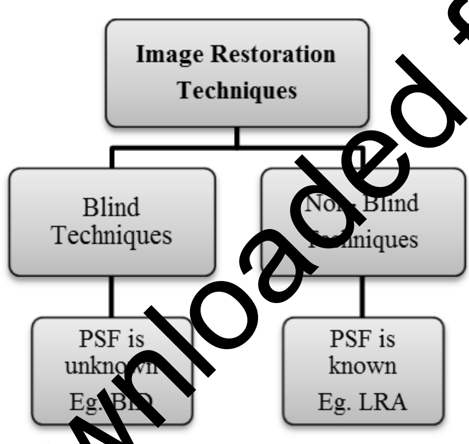

Fig. 2. Image Restoration Techniques

II. BLIND IMAGE DECONVOLUTION

BID is a Blind technique of image restoration which restores the degraded image that is blurred by an unknown PSF. It is a deconvolution technique that permits recovery of the target image from a single or set of blurred images in the presence of a poorly determined or unknown PSF [9][15]. In this technique firstly, we have to make an estimate of the blurring operator i.e. PSF and then using that estimate we have to deblur the image [14]. This method can be performed iteratively as well as non-iteratively. In iterative approach, each iteration improves the estimation of the PSF and by using that estimated PSF we can improve the resultant image repeatedly by bringing it closer to the original

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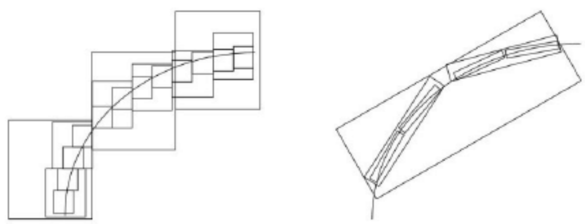
image. In non-iterative approach one application of the algorithm based on exterior information extracts the PSF and this extracted PSF is used to restore the original image from the degraded one [10].

III. CURVELET TRANSFORMATION

In the year 1999, an anisotropic geometric wavelet transform, named ridgelet transform, was proposed by Candes and Donoho [4]. The ridgelet transform is optimal at representing straight-line singularities. Unfortunately, global straight-line singularities are rarely observed in ral applications. To analyze local line or curve singularities, a natural idea is to consider a partition of the image, and then to apply the ridgelet transform to the obtained sub-images. This block ridgelet-based transform, which is named curvelet transform, was first proposed by Candes and Donoho in the year 2000 [2][5]. Curvelets are designed to handle curves using only a small number of coefficients. Hence the Curvelet handles curve discontinuities well [6]. The curvelet transform that inherits the ridgelet transform, was introduced to represent edges better than all known image transforms [3]. To analyze local line or curve singularities, a natural idea is to consider a partition of the image, and then to apply the ridgelet transform to the obtained sub-images.



a b

Fig. 3. Edges produced by a) wavelets b) curvelet

A. Process of Curvelet Transform

The whole process of curvelet transform is divided into four stages. Whenever we want to find out curvelet transform of an image then we have to go through each of the four stages.

These stages are basically a procedure to implement the curvelet transform using various images. All these stages are given below [7].

- Sub-band decomposition
- Smooth partitioning
- Renormalization
- Ridgelet Analysis

1) Sub-band decomposition

It is a stage which divides the image into sevel resolution layers. Each layer contains details of different frequencies:

$P_0 \rightarrow$ Lowpass filter

Δ_1, Δ_2, …Band-pass (high-pass) filters

Here,a bank of subband filter P_0, (Δs, s >=0). The object f is filter into subbands

$$f \mapsto (P_0 f, \Delta_1 f, \Delta_2 f, \ldots) \qquad (3$$

2) Smooth Partitioning

It defines a collection of smooth window wQ(x1 , x2) localized around dyadic squares.

$$h_Q = w_Q \cdot \Delta_s f \qquad (4)$$

The image becomes smooth after multiplying wQ function. The partitioning make easier to analyze local line or curve singularities.

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3) Renormalization

In this stage of the procedure, each „square" resulting in the previous stage is renormalized to unit scale:

$$g_Q = T_Q^{-1} h_Q \qquad (5)$$

4) Ridgelet Analysis

Last stage is ridgelet analysis. Here, each normalized square is analyzed in the ridgelet system:

$$\alpha_{(Q,\lambda)} = \langle g_Q, \rho_\lambda \rangle \qquad (6)$$

All the four stages are shown in Fig. 4.

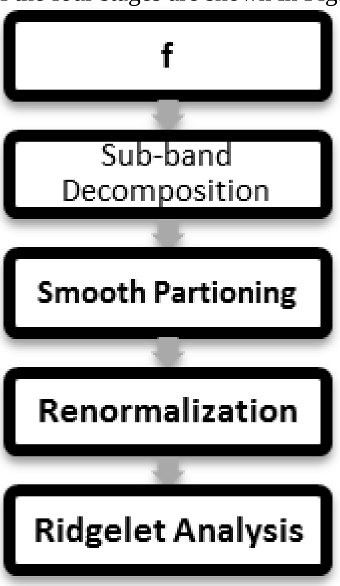

Fig. 4. Stages of Curvelet Transform

IV. METHODOLOGY

All the implementation work is done in MATLAB R2012b. For experimentation seven different images were considered. All these were first degraded using Gaussian blur and Gaussian noise. The degraded images were then reconstructed using the proposed technique which is based on BID and curvelet transform.

The proposed technique is named as Improved-BID i.e. I-BID. I-BID basically combines the effects of BID and Curvelets. The edges of the image produced by BID are not sharp and contain ringing effect. Noise was also not removed successfully.

All these shortcomings are removed by combining BID with Curvelet transform. I-BID is an improved version of BID based on the blind deconvolution of noisy images using curvelet transform. Curvelet Transform is very efficient in edge detection and noise reduction. The features of both BID and Curvelet are combined to produce I-BID.

The whole architecture of the proposed work is explained in the flowchart shown as Fig. 6. First of all, an input image is read and then degraded using some degradation function i.e. Gaussian blur and Gaussian noise. The degraded image is then restored using the BID technique. The resultant image of BID is then restored using Curvelet transform.

For performance evaluation, three performance metrics are used i.e. MSE (Mean Square Error), PSNR (Peak Signal to Noise Ratio) and RMSE (Root Mean Square Error) [17].

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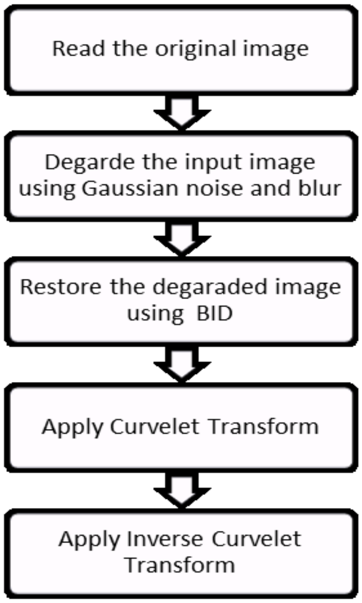

Fig. 6. Overall Architecture

V. EXPERIMENTAL RESULTS

The proposed technique is implemented and analyzed using the seven considered input images the values of all the three performance metrics are evaluated for all images. The experimental results of the proposed technique are compared with the existing work. It is implemented and investigated using seven different images of different sizes. Images from size 127 x127 to size 768 x 768 are considered for obtaining a wide range of experimental results.

TABLE I. PERFORMANCE EVALUATION OF BID AND IBID

Performance / Parameters	MSE		PSNR		RMSE	
	BID	I-BID	BID	I-BID	BID	I-BID
Image1.jpg (127x127)	9.90	8.20	87.98	89.79	3.15	2.86
Image2.jpg (183x183)	7.9[illegible]	4.86	90.13	95.01	2.83	2.21
Image3.jpg (200x200)	7.58	4.27	90.65	96.30	2.75	2.07
Image4.jpg (256x256)	25.30	17.23	78.59	82.36	5.03	4.15
Image5.jpg (400x400)	23.24	15.08	79.45	83.69	4.82	3.88
Image6.jpg ([illegible]00x[illegible]00)	15.05	6.05	83.79	92.83	3.88	2.46
Image7.jpg (768x768)	18.75	11.90	81.59	86.06	5.57	3.45

Graphically, these performance results can be visualized with the help of line charts. There are three plots corresponding to MSE, PSNR and RMSE values which are shown in Fig. 7, Fig. 8 and Fig. 9 respectively. From the three line charts the comparative results of BID and I-BID are validated.

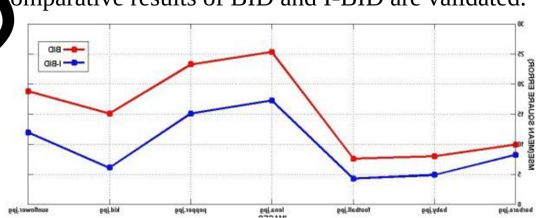

Fig. 7. Line chart for MSE

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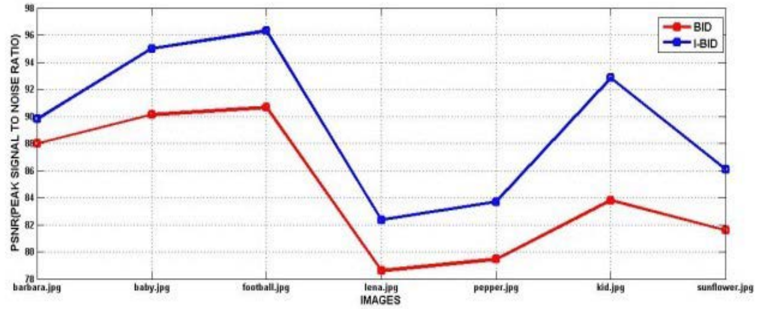

Fig. 8. Line chart for PSNR

Table 1 contains the values of MSE, PSNR and RMSE corresponding to BID and I-BID. It is clear from the table that I-BID is having lower MSE and RMSE values than BID for each input image. Also, I-BID is having high PSNR values than BID. These values prove the better performance of the work.

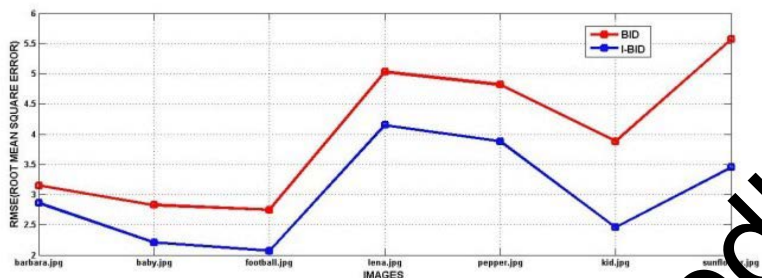

Fig. 9. Line chart for RMSE

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CONCUSION AND FUTURE SCOPE

To conclude, the experimental results of the proposed work i.e. I-BID are better than that of the existing work. The quality of the image produced using I-BID is better than the earlier works both visually and quantitatively. In future, this work can be extended to cover other types of noises and blurs.

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