Recovery of Grayscale Image from Its Halftoned Version Using Smooth Window Function

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Abstract— **In a grayscale image of 256 levels, it is indistinguishable between intensity levels hence it is called continuous tone image. In a binary image the mark and space are distinguishable but sharp change in intensity level makes the quality of the image very poor. The half tone image is also a binary image but varying the size of pixels and its density improves the quality of the image. The halftone image here can be considered as the truncated normalized version of continuous tone image. Based on this concept smoothing the transition of half tone image by convolutional operator with a smooth window function can recover the continuous tone image. Finally noise grains are eliminated applying DWT (Discrete Wavelet Transform), gives the much closed perception of grayscale image. Although the similar concept is applied in blurring of a continuous tone image but in this paper similar concept is applied to half-tone operation to avoid the complexity of RI (Recursive Inverse) and RWI (Regularized Wiener Inversion) algorithm.**

Index Terms— **Convolution, cross correlation co-efficient, discrete wavelet transform, Floyd-Steinberg algorithm, process time**

I. Introduction

With advancement of multimedia product and communication, the storage capacity is a prime consideration for an individual machine or nodes of network. Halftone images deals with the way to compromise between image quality and storage capacity of devices. A halftone image is actually a binary image with different format. It consists of dots of different sizes, different colors, and sometimes even different shapes. To represent dense or dark area larger dots are used whereas smaller dots are used for lighter areas. Actually smaller dots produce lighter grays and off-whites, while larger dots can lead to dark gray or black areas in an image gives the flavor of grayscale image. Basic concept of halftone image lies in the fact that, the low frequency component of a halftone image is kept approximately same as the continuous tone image but the high frequency component of the halftone image is not correlated with its low frequency component summarized in [1]. The above idea does not satisfy us to achieve a good quality image but the main satisfaction comes from human visual system which acts as a low pass filter at a suitable distance. Therefore from a distance halftone image gives the illusion of continuous tone (rich depth of tone) image using its true white and true black pixels.

Thus the halftone image reduces the difference between grayscale image and binary image from observer's point of view and gets popularity in printing of newspapers, magazines, books, as well as fax machines and printers. Because halftone image requires significantly less ink compared to continuous tone image. In printer and publishing applications halftone watermarking is also used explained in [4] along with its security issue. Another important application of haltoning concept is in video conferencing. In video conferencing system reduction of bandwidth is vary essential to cope with the channel capacity of the link. In such system combination of lossy and lossless compression is applied to make tradeoff between bandwidth and video quality. In such case halftoning can be included as the portion of lossy compression depicted in [2].

Digital halftoning method has two parts: ordered dithering and error diffusion shown explicitly in [1] and [3] along with inverse halftoning algorithm. In inverse halftoning technique a halftone image is converted into grayscale images. There exist several common inverse halftoning methods like wavelet transform method of [5], digital filtering method of [6]. In [7] authors performed half-tone operation using 7×7 FIR filter and finally computes peak signal to noise ratio (the ratio of the maximum possible pixel value to standard deviation between original and noisy image in logarithmic scale) to check the fidelity of recovered image. Some special frequencies which preserve most of the contents of the original image are kept and halftone noises are eliminated using wavelet decomposition performed in [8]. In pattern extracting method of [9] the original image is partitioned into nonoverlapping blocks of 3×3 then the concept of pattern recognition is applied to recover the grayscale image.

In this paper, we focus on the recovery of halftone image. Our analysis is actually the combination of both [7] and [8] but we select established IIR filters instead of FIR filter of [7]. We use eigenvalues and cross-correlation of images to measure fidelity of recovered image instead of PSNR of [7]. We applied DWT on first stage recovered signal instead of direct halftone image of [8]. At first, several image preprocessing methods are applied on the original gray-scale image. Floyd-Steinberg algorithm is used to convert the gray-scale image to halftone image. Then the image is convoluted with window function and finally it is denoised using Discrete Wavelet Transform (DWT). The paper is organized like: section II is 'system model' which includes four subsections provide theoretical analysis of halftoning and its inverse operation, section III deals with the results based on section II and finally section IV concludes the entire analysis.

II. SYSTEM MODEL

This section deals with generation of binary image that provides the illusion of original continuous toned gray scale image. The entire work is divided into four subsections and the operation of corresponding sub-sections is given below.

A. Image Preprocessing

Preprocessing is a common operation with images at the lowest level of abstraction. The aim of pre-processing is to improve the image data that suppresses unwanted distortions, noise and to enhance some image features for further processing.

B. Halftone Algorithm

Half tone image is actually a binary image of dot of variable in size gives better visualization of an observer compared to ordinary binary image. Most widely used halftoning methods are: order dithering, error diffusion, dot diffusion and least square error. In this paper we use error diffusion under Floyd - Steinberg mask to produce half toning dot [10-11]:

$$B = \frac{1}{48}\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & A & 7 & 5 \\ 3 & 2 & 5 & 6 & 3 \\ 2 & 5 & 3 & 5 & 2 \end{bmatrix} \tag{1}$$

This algorithm diffuses the quantization error of a pixel to its neighboring pixel. It scans the input image from left to right, top to bottom. While scanning, it quantizes the pixel values one by one and the quantization error is transferred to the neighboring pixel; provided it does not affect the pixels that already have been quantized. If a number of pixels have been rounded downwards, it becomes more likely that the next pixel is rounded upwards. The error of quantization is close to zero on an average.

C. Convolution with Smooth Window Function

Window functions are smoothly varying mathematical functions are used to truncate a signal of infinite duration to bring it in finite range without proving ripples of Gibb's phenomena. If any signal in time domain is truncated with sharp rectangular window function, generates huge ripple in frequency domain. The reverse is also true from frequency to time domain. A two dimensional smooth Gaussian window function, *W(u, v)* under frequency domain (represented as *u-v* domain in this paper) is used here to select the frequency of finite rage that are zero-valued outside the chosen interval. It is constant within a specific interval and zero elsewhere. Multiplication in the frequency domain (*u-v* domain) is equivalent to convolution in the time (*x-y* domain) domain [12].

For an LTI system, if *x(t)* is the input signal and *h(t)* is the corresponding impulse response of the system then the output of the system,

$$y(t) = x(t)*h(t) \tag{2}$$

taking fourier transform,

$$Y(f) = X(f).H(f) \tag{3}$$

Where, $y(t) \leftrightarrow Y(f)$, $x(t) \leftrightarrow X(f)$, $h(t) \leftrightarrow H(f)$

Similarly the spectrum of an image *i(x,y)* is *I(u,v)* found from $i(x, y) \leftrightarrow I(u,v)$. The Gaussian filter in time and frequency domain is related as, $g(x, y) \leftrightarrow G(u,v)$. Now the filtered or smoothen image in *u-v* and *x-y* domain are,

$$I'(u,v)=I(u,v).G(u,v) \tag{4}$$

$$i'(x,y)=i(x,y)*g(x,y) \tag{5}$$

D. Denoising with Threshold

De-noising deals with to remove unwanted noise in order to restore the original image. Wavelet transform provides us with one of the methods for image denoising [13-15]. Wavelet transform, due to its excellent localization property, has rapidly become an indispensable signal and image processing tool for a variety of applications, including de-noising and compression.

Noise on image reveals itself as fine-grained structure results in small scale coefficient after wavelet transform. Image filtering is equivalent to discard of these coefficients. A threshold level is selected to discard the coefficients such that edge information remains unaltered. Because coefficients pertinent to edges are very closed to that of noise hence discarding technique may leads huge distortion to image. The entire process of recovery of desired image is shown in Fig.1.

In result section we measure the percentage of similarity between original grayscale image *i(x,y)* and $i_r(x,y)$ based on cross correlation co-efficient expressed as [16],

$$\rho_{i,i_h}(l) = \frac{\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} i(x, y)\, i_h(x+l,\, y+l)}{\sqrt{E_i E_{i_h}}} \tag{6}$$

where,

$$E_i = \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} i^2(x, y),\; E_{i_h} = \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} i_h^2(x, y) \text{ and}$$

$$l = 0, \pm 1, \pm 2, \dots \dots \dots, \pm(N-1)$$

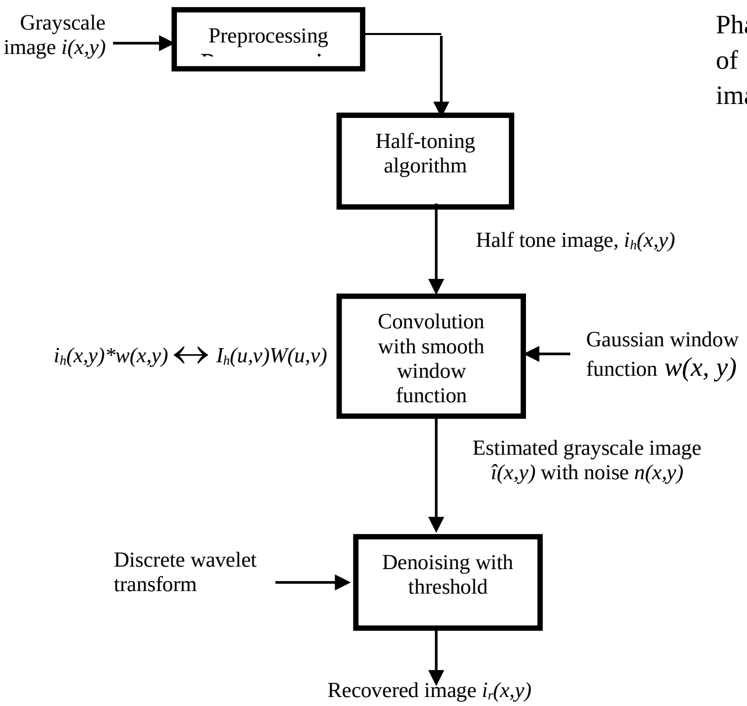


Fig.1 Recovery of a grayscale image from halftone image

Finally the six largest eigen values (in normalized form) of the matrices **A** and **B** of original grayscale and recovered images, respectively, are compared and found very closed. Let the normalized eigen value of each of the matrix is λ. Let us we can consider the eigen values of **A** and **B** are $n\lambda$ and $m\lambda$ respectively where n and m are constant. The linear equation relating eigen values and eigen vectors for each of the matrix are [17],

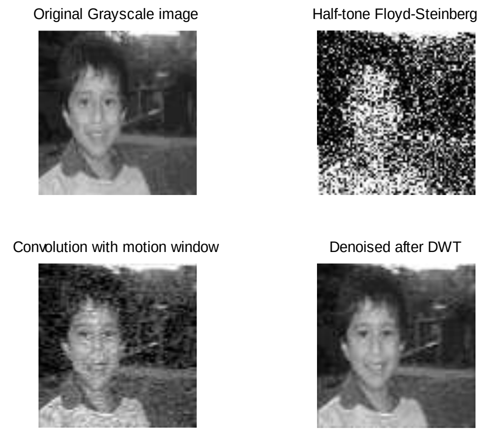
$$(\mathbf{A} - n\lambda\mathbf{I})\mathbf{v} = 0 \qquad (7)$$

$$(\mathbf{B} - m\lambda\mathbf{I})\mathbf{u} = 0 \qquad (8)$$

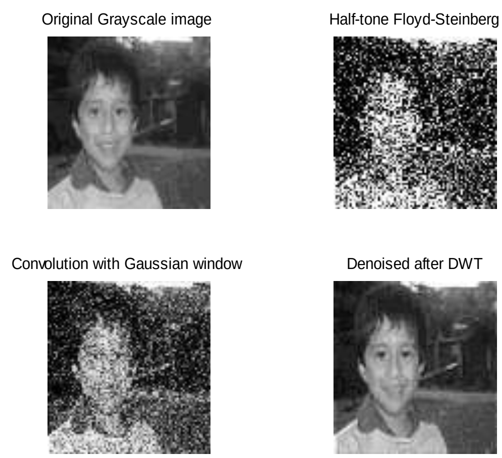
Where **v** and **u** are the eigen vectors of matrix **A** and **B** respectively. From (7) and (8) we can derive, **A**= *(n/m)* **B** i.e. the original grayscale image can be recovered from the denoised image matrix simply multiplying it by a constant *n/m*.

III. Results and Discussion

To verify the result we took three images shown in Fig 2. Each part of the figures shows the original grayscale image, halftone image, recovered image using smooth window function and denoised image using DWT. In this paper we use four smooth window functions: Gaussian window, Motion window, Disk window and Gabor window. At a glance, the original grayscale image resembles the final desired image. Actually the intermediate image is a binary image of very small in size (which is actually the eight times compressed version of the original image) but provide the way to generate the illusion of original binary image. Now the transmission of half tone binary image of small in size is possible using Binary Phase Shift Keying (BPSK). This can help the communication of wireless sensor network and telemedicine system where image communication is essential.



(a)



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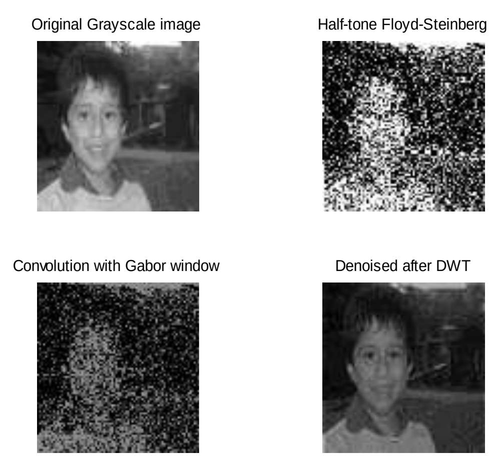

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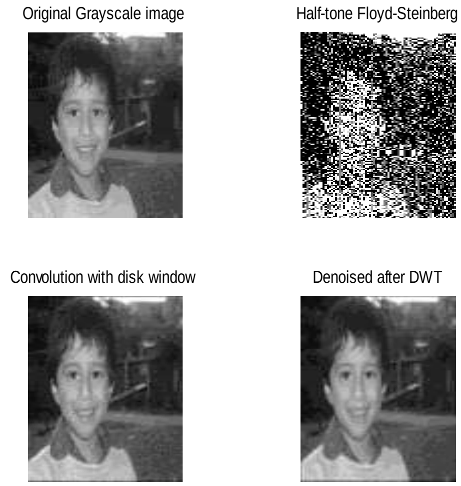
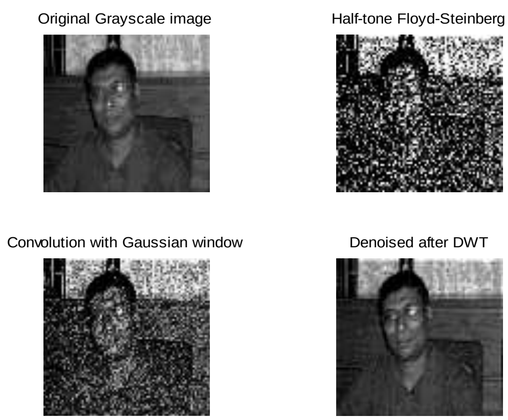
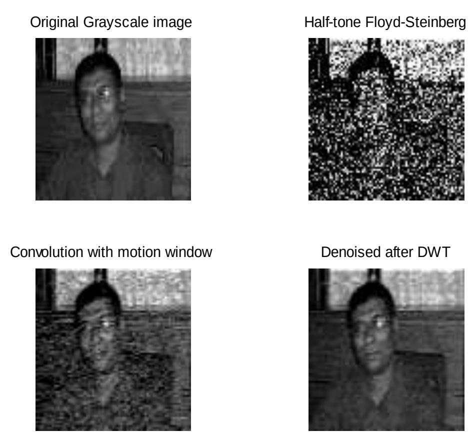


(d)

Example image-1



(a)



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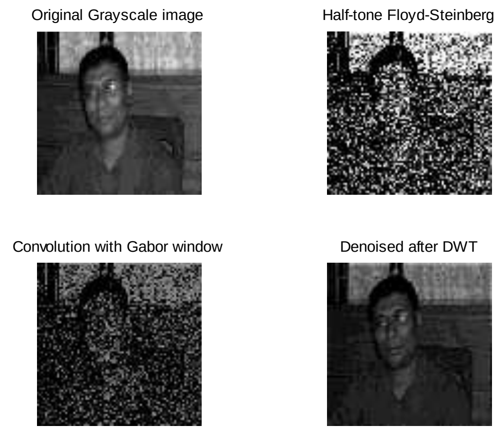

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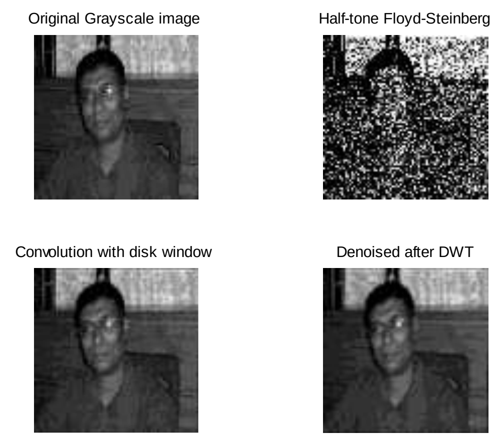
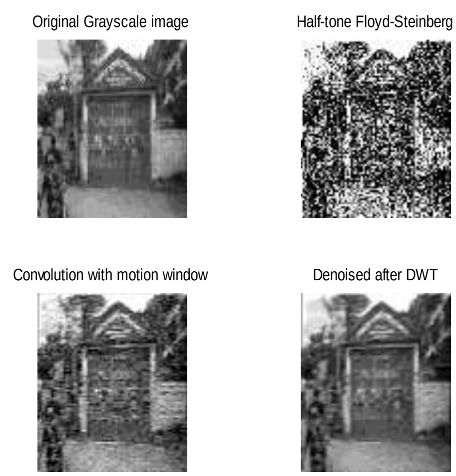
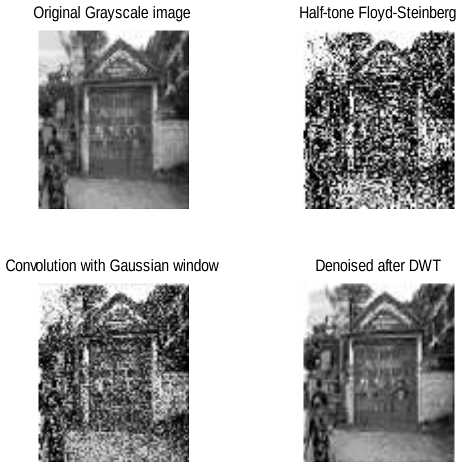


(d)

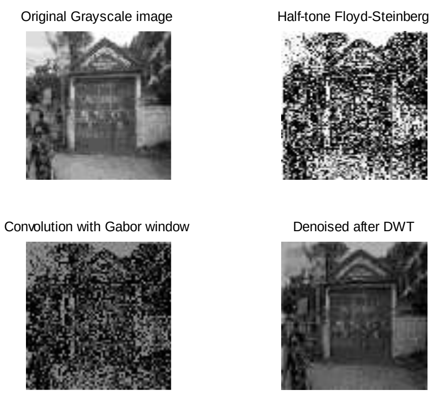
Example image-2



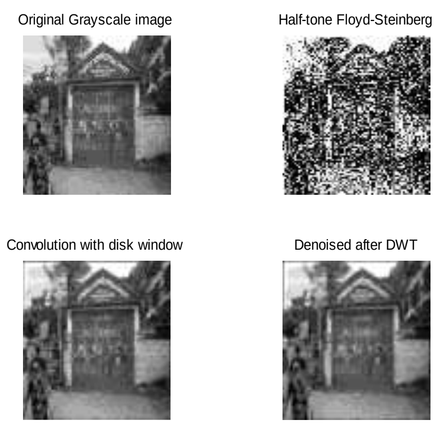
(a)



(b)



(c)



(d)

Example image-3
(a) Gaussian window (b) Motion window
(c) Disk window (d) Gabor window
Fig.2 Illusion of original grayscale, half tone, smooth image after convolution with window function and denoised image using DWT

TABLE-I: CROSS CORRELATION OF THREE TEST IMAGES WITH PROCESSING TIME

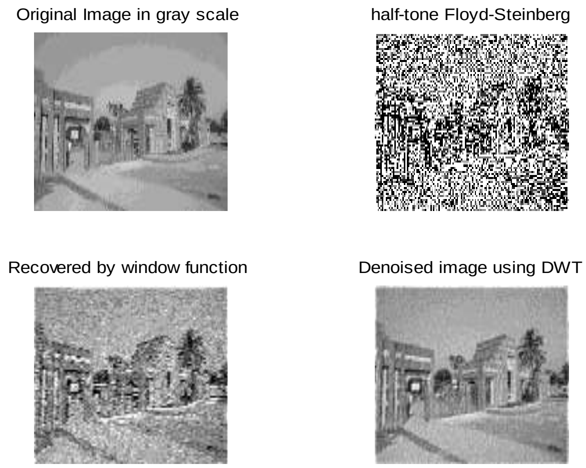
Image no.	**Window function**	**Cross correlation co-efficient, ρ_{i,i_h}**	**Process time in S**
1	Gaussian	0.9716	1.7160
2		0.9518	1.7160
3		0.9219	2.6988
1	Motion	0.9725	1.7940
2		0.9504	1.7004
3		0.9270	2.9016
1	Disk	0.9761	1.7628
2		0.9678	1.8096
3		0.9346	2.6988
1	Gabor	0.9685	1.6380
2		0.9475	1.6692
3		0.9175	2.8080

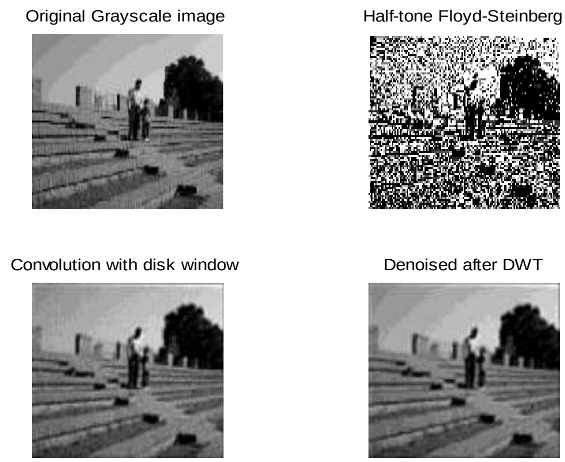
The original and the final denoised image resemble to be the same but mathematically we verified their similarity using cross correlation co-efficient of the images, six largest eigen values of the images. TABLE II shows the normalized eigen values (six largest) for three original test images and TABLE III shows the similar results of recovered images (shown in appendix-2). The values of TABLE II and III are found very closed. TABLE-I shows the value of cross correlation between original and recovered images found above 91% for each case. Here we used only four window functions where the relative performance are found almost same but in context of cross correlation coefficient ‘disk window’ shows the best result and ‘gabor window’ provides the lowest values. The process time depends on images but not on window function visualized from table-I. For better visualization of original and recovered images we included six additional images of jahangirnagar university campus shown in appendix-1.

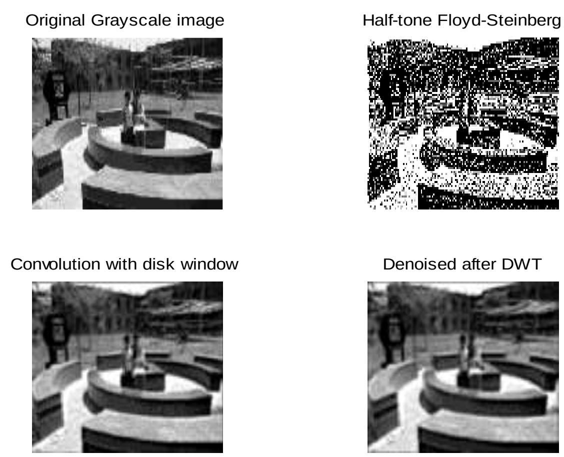
IV. Conclusion

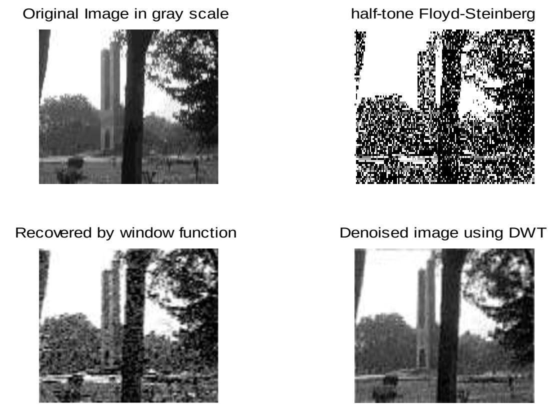
In this paper we introduced a method of recovery of grayscale image from its halftone version. Although the recovery is lossy but provides good impression at a glance. The entire work is done for grayscale image can be extended to RGB image. The process time used here is found too small compared to other existing models at the expense of quality of the image. The main application of the paper is: transmission of halftone image (actually binary image of 0 and 1) through network requiring very low BW (Bandwidth) compared to grayscale image transmission. At receiver the estimated grayscale image is recovered using concept of the paper.

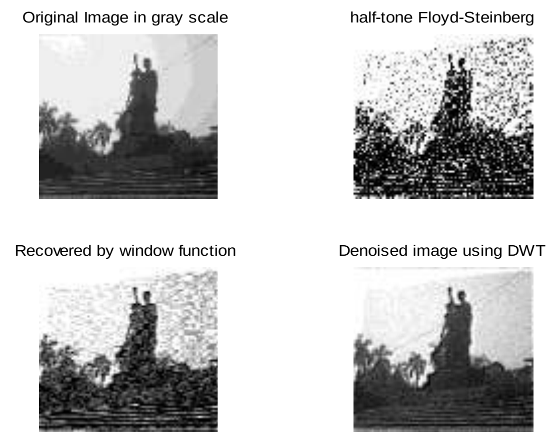
Appendix-1











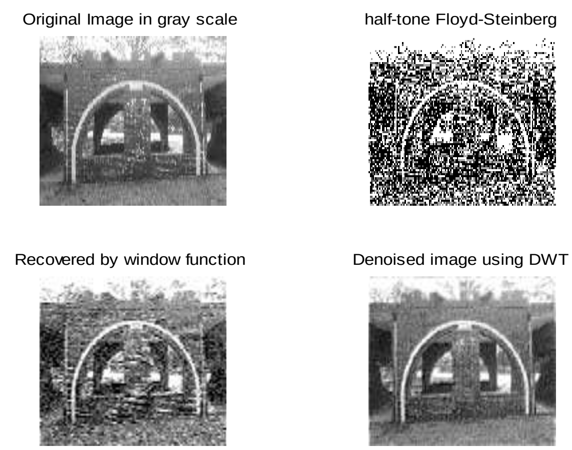


Fig.A.1 Few images of Jahangirnagar university campus to compare original and recovered images

Appendix-2

TABLE II: SIX LARGEST NORMALIZED EIGEN VALUES OF ORIGINAL IMAGE

Image no.	Window function	1st largest eigen values of original image (normalized)	2nd largest eigen values of original image (normalized)	3rd largest eigen values of original image (normalized)	4th largest eigen values of original image (normalized)	5th largest eigen values of original image (normalized)	6th largest eigen values of original image (normalized)
1	Gaussian	1.0000	-0.1688	0.1265	0.0425 + 0.0445i	0.0425 - 0.0445i	-0.0020 + .0366i
2		1.0000	0.1186	-0.0322 + 0.0425i	-0.0332 - 0.0424i	-0.0416 - 0.0014i	-0.0416 + 0.0014i
3		1.0000	0.1293	-0.0674 0.0094i	0.0394 - 0.0542i	-0.0629 - 0.0149i	-0.0629 + 0.0149i
1	Motion	1.0000	-0.1657	0.1273	0.0425 + 0.0445i	0.0425 - 0.0445i	-0.0020 + 0.0366i
2		1.0000	0.1193	-0.0320 + 0.0427i	-0.0332 - 0.0424i	-0.0416 - 0.0014i	-0.0416 + 0.0014i
3		1.0000	0.1272	-0.0670 + 0.0099i	0.0394 - 0.0542i	-0.0629 - 0.0149i	-0.0629 + 0.0149i
1	Disk	1.0000	-0.1636	0.1275	0.0425 + 0.0445i	0.0425 - 0.0445i	-0.0020 + 0.0366i
2		1.0000	0.1196	-0.0320 + 0.0428i	-0.0332 - 0.0424i	-0.0416 - 0.0014i	-0.0416 + 0.0014i
3		1.0000	0.1264,	-0.0659 + 0.0070i	0.0394 - 0.0542i	-0.0629 - 0.0149i	-0.0629 + 0.0149i
1	Gabor	1.0000	-0.1705	0.1262	0.0425 + 0.0445i	0.0425 - 0.0445i	-0.0020 + 0.0366i
2		1.0000	0.1180	-0.0319 + 0.0434i	-0.0332 - 0.0424i	-0.0416 - 0.0014i	-0.0416 + 0.0014i
3		1.0000	0.1291	-0.0671+ 0.0095i	0.0394 - 0.0542i	-0.0629 - 0.0149i	-0.0629 + 0.0149i

TABLE III: SIX LARGEST NORMALIZED EIGEN VALUES OF RECOVERED IMAGE

Image no.	Window function	1st largest eigen values of recovered image (normalized)	2nd largest eigen values of recovered image (normalized)	3rd largest eigen values of recovered image (normalized)	4th largest eigen values of recovered image (normalized)	5th largest eigen values of recovered image (normalized)	6th largest eigen values of recovered image (normalized)
1	Gaussian	1.0000	-0.1603	0.1245	0.0429+0.0430i	0.0429 - 0.0430i	-0.0025 + 0.0374i
2		1.0000	0.1231	-0.0332 + .0424i	-0.0322 - 0.0425i	-0.0467 - 0.0164i	-0.0467 + 0.0164i
3		1.0000	0.1271	0.0394 + 0.0542i	-0.0674+ 0.0094i	0.0449 - 0.0494i	0.0449 + 0.0494i
1	Motion	1.0000	-0.1603	0.1245	0.0425 + 0.0415i	0.0425 - 0.0415i	-0.0027 + 0.0368i
2		1.0000	0.1231	-0.0332 + 0.0424i	-0.0320 - 0.0427i	-0.0426 - 0.0119i	-0.0426 + 0.0119i
3		1.0000	0.1271	0.0394 + 0.0542i	-0.0670 - 0.0099i	0.0425 - 0.0478i	0.0425 + 0.0478i
1	Disk	1.0000	-0.1603	0.1245	0.0423 + 0.0409i	0.0423 - 0.0409i	-0.0027 + 0.0366i
2		1.0000	0.1231	-0.0332 + 0.0424i	-0.0320- 0.0428i	-0.0411 - 0.0122i	-0.0411 + 0.0122i
3		1.0000	0.1271	0.0394 + 0.0542i	-0.0659 - 0.0070i	0.0424 - 0.0471i	0.0424 + 0.0471i
1	Gabor	1.0000	-0.1603	0.1245	0.0429 + 0.0437i	0.0429 - 0.0437i	-0.0024 + 0.0370i
2		1.0000	0.1231	-0.0332+ 0.0424i	-0.0319 - 0.0434i	-0.0460 - 0.0178i	-0.0460 + 0.0178i
3		1.0000	0.1271	0.0394 + 0.0542i	-0.0671 - 0.0095i	0.0446 - 0.0494i	0.0446 + 0.0494i

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