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Image Enhancement using Dynamic Stochastic Resonance in Discrete wavelet Domain

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Abstract— Many images like medical images, satellite images, Arial images and even life photographs suffer from noise. Image enhancement techniques are used to improve the visual appearance of images by reducing noise from images. In this paper, a dynamic stochastic resonance (DSR) based algorithm is proposed to improve the visual quality by removing noise from digital image. Stochastic resonance (SR) is a phenomenon in which the performance of a system can be improved by addition of noise. In proposed algorithm salt and pepper noise is added in image with different variance. After applying proposed DSR technique, resultant image is enhanced and results are better in terms of Noise Standard Deviation (NSD), Mean Square Difference (MSD) and Signal to Noise Ratio (SNR) when compared with other techniques such as Gaussian low pass filtering, soft thresholding and hard threholding of wavelet coefficient.

Index Terms — Image enhancement, DWT, Noise, Dynamic Stochastic Resonance, LPF.

1 INTRODUCTION

In recent years, the need of digital image processing for military, medical and industrial purposes is growing day by day. Many researches have been done in this field. Digital image processing has been changed from a specialized subject to a new research tool. Digital image processing deals the action on digital images by using a digital camera. Digital image processing is subfield of signals and systems but mainly it focuses on images. The captured images may suffer some distortions. There are various reasons like some environmental conditions, wrong settings of the lens etc. [12]. So the image is often infected by noise while the image is digitalized, transported and recorded. Generally, noise is considered to be a nuisance or destructive in nature which decreases the quality of an image. Hence, image enhancement and denoising techniques are used to improve the colour, contrast, visualisation, and detailing of the images. So, the image enhancement technology plays a very important and vital role in image processing.

Image enhancement is mainly classified into two categories namely spatial domain method and frequency domain method. The spatial domain method works on the two dimensional space where on image pixels gray values are altered or directly manipulated by using methods like neighbourhood average, median filtering, geometric filtering etc. Whereas the frequency domain methods need image intensity values to be transformed to some other domains by using transformation models like DFT, DWT and DCT etc. Once, the image is in appropriate domain, there are many techniques which can be performed to increase the contrast of image or suppress the noise [1]. A comprehensive survey of image enhancement techniques has been published in [2, 3].

Major numbers of the techniques in literature have focused on the enhancement of gray level images in the spatial domain. Homomorphic filtering, high pass and low pass filtering, un-sharp masking, histogram equalization, constant variance enhancement etc are few important examples of such techniques [4, 5]. These techniques have also been applied for the enhancement of colour images [4, 6] in the RGB space.

The colour image enhancement techniques are distinct from gray scale image enhancement techniques. Because the colour image enhancement has two constraints i.e. one constrain is to maintain the originality of natural colour of the original image and second constrain is to maintain the detailing or information loss which is contained in the luminance of the image.

According to the colour space conversion, colour image enhancement can be divided into two categories. These are (1) Color image enhancement based on RGB space and (2) The enhancement based on transformed space.
RGB colour space includes some techniques like 3-D histogram equalisation [7, 8], gamma correction, homomorphic filtering [9] and multi-scale retinex [10, 11]. The enhancement of colour images has become a more challenging task because of the added dimension and added complexity of colour perception. By using RGB colour space based enhancement technique one can enhance the brightness and contrast but it leads to colour distortion or shifting.

In enhancement based on transformed space, the images in RGB colour space are transformed into different colour space such as HSV, YUV, YCbCr, XYZ, etc. In [12, 13] an input RGB colour image is converted into HSV colour image. Image enhancement technique is applied to the value component of the image and saturation component is enhanced by stretching its dynamic range to get rich colour display. Generally the hue component is preserved because change in H component could degrade the colour balance between the HSV components. In [14] an input RGB image is converted into YCbCr colour space by resizing that input image and applying DCT compression. Then, the luminance part of that input image is converted into vectors and its scaling coefficients are calculated. To obtain Y, U, V, DCT is applied on all three colour spaces.

Noise is considered to be a nuisance which decreases the quality of an image, but sometimes noise can be added to increase the SNR value of the weak signals [15, 16, and 17]. On the contrary, stochastic resonance is a phenomenon in which noise can be used to enhance the system performance. It is a counter-intuitive phenomenon in a non linear system where the presence of noise is essential for optimal system performance. Recently some work is done on the application of stochastic resonance for image enhancement of gray scale image [18, 19, 20] but more exhaustive study is required in this area to modify the existing algorithms for better image enhancement, computation requirement and computational speed.

2. RELATED WORK

Rajib Kumar Jha [21] et.al. proposed two SR based techniques for enhancement of low contrast image. An expression has been derived for optimal threshold by using Gaussian noise to increase the standard deviation iteratively to the low contrast image till the quality of enhanced image reaches maximum. In second technique, another expression has been derived for optimum noise standard deviation (σoptimum) which maximizes the value of SNR. In [22] they derived an expression to optimally detect the edges in an image using the vibrating noise for the retina.

In [23] they used non DSR to improve the system performance of adaptive histogram equalisation by using stochastic resonance (SR) in medical images. In [24] a non-linear, non-dynamic stochastic resonance based technique is introduced to enhance the low and dark contrast images. A low contrast image is treated as a sub-threshold signal and noise is applied to improve its contrast. In this, they used the concept of stochastic resonance in which external noise is added to minimize the effect of internal noise of the low contrast input image. The external noise is randomly selected and added in input image iteratively and at last find out the hard-threshold by overall averaging.

R. Chouhan [25] et.al. remarked a dynamic stochastic resonance technique in DWT domain for enhancing the images that are dark, grayscale and coloured perception for improvement of performance of input signal through addition of external noise. Intrinsic noise of image for contrast enhancement is used in their technique which is capable of enhancing the image without spot artifacts, blocking and ringing. The algorithm is optimized and made adaptive for measurement of performance as distribution separation measure and aims to background enhancement that generally have basis upon standard deviation and entropy. Their technique produced better results in terms of complexity, colour preservation etc.giving fine enhancement of extremely dark images. For grayscale and coloured dark images their scheme give better visual perception and contrast quality. This paper thus, focuses on Dynamic Stochastic Resonance and the modification of existing DSR techniques for better image enhancement while keeping low computational complexity.

3. DYNAMIC STOCHASTIC RESONANCE

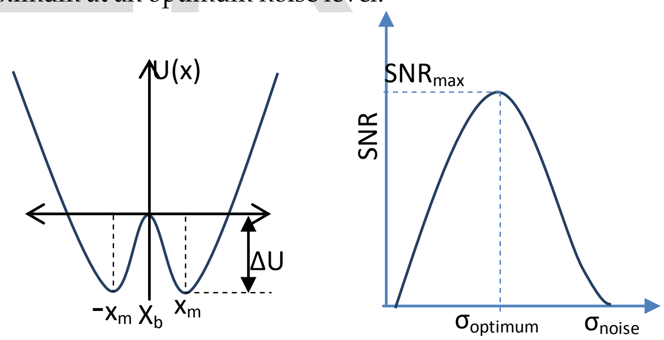
The concept of physics called dynamic stochastic resonance (DSR) is used in image enhancement. Maximum algorithms of image enhancement and denoising suppress the presence of noise from the system or image, but do not totally remove it. As discussed in earlier sections, generally it is a notion that noise is a nuisance which makes a system worse. But on the contrary, stochastic resonance is a phenomenon in which noise can be used to increase the system performance and to enhance the image.

The system should have three basic properties to exhibit the SR:-

1. A non linearity in terms of threshold
2. A sub-threshold signal like a signal with small amplitude
3. A source of additive noise

Basically, this phenomenon occurs in bi-stable systems frequently or in systems with threshold like behaviour. As in the recent studies, non-linear systems are added with noise to amplify the weak signals and increase the signal to noise ratio. SR is divided into three categories as non-linear dynamic SR, non-linear non-dynamic SR and supra-threshold SR.

The mechanism of SR shows that the weak signal at lower noise intensities is not able to cross the threshold value and give a very low SNR value and at the large noise intensities the output are also dominated by the noise and give the low SNR value. So for the maximum noise intensities, the optimum noise is added to the weak signal to cross the threshold and give the maximum SNR value. Fig 1 plot of SNR as a function of noise intensity which shows a maximum at an optimum noise level:-



a) b)

Fig. 1 SR in double-well potential

a) SNR against noise density
b) Bi-stable double-well potential system

The theory of stochastic resonance was invented by the study of Earth's climate in 1981-1982. The statistical data analysis explains that interglacial transition is a random variable with a cycle time of one million years. The eccentricity of the earth is the only factor which changes with the same periodicity. So eccentricity change of the magnitude is about 0.1 % which is quite small and such a small change in eccentricity can cause the drastic changes in earth's climate. So the concept of stochastic resonance was developed by using

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this natural phenomenon. One of these theories was described by Benzi et.al. [15, 26] to explain this global climate Double well potential theory was used. Benzi et.al. double well model for the global climate is explained in [27].

In an analogy of Benzi's double well model for interglacial changes or in ice ages, all the pixel values of an image can be treated as the varying parameter in the double well. For example, intensity of image pixel can be taken as the position of a particle in a double well. Now, if a weak signal is present which unable to cross the threshold then a white Gaussian noise is added and this weak signal cross double well form lower contrast to higher contrast. As shown in fig 1 b), the minima at the first well at $x = -x_m$ represent the image pixel values in low contrast region. The added periodic input signal is weak and cannot cross this minima to reach the second minima at $x = x_m$ which corresponds to image pixel values in high contrast region. But if a Gaussian noise is added to the system (or the internal noise is used) the system can transit from low contrast to high contrast region at a particular optimum noise level. The signal to noise ratio is also maximized as given in Fig 1 a).

For the analysis of transition state of a particle between the double well minima, the theory of Brownian model of a particle is placed in double well potential system is used.

A nonlinear dynamic system that exhibits stochastic resonance is modelled with the help of Langevin equation of motion given in [27] in the form of given below:

$$m\frac{d^2x(t)}{dt^2} + \gamma\frac{dx(t)}{dt} = -\frac{dU(x)}{dx} + \sqrt{D}\xi(t) \quad (1)$$

For the image enhancement, the term $m\frac{d^2x(t)}{dt^2}$ can be neglected and γ =1 then,

$$\frac{dx(t)}{dt} = -\frac{dU(x)}{dx} + \sqrt{D}\xi(t) \quad (2)$$

Where U(x) is the bi-stable potential given in (3), D is the noise variance and $\xi(t)$ is the noise:

$$U(x) = -a\frac{x^2}{2} + b\frac{x^4}{2} \quad (3)$$

here a and b are positive bi-stable double well parameters. In figure 1(b) the potential double well is stable at xm which is given by:

$$x_m = \pm\sqrt{a/b} \quad (4)$$

These two minima are separated by a energy barrier of height.

$$\Delta U = (\frac{a^2}{4b})$$

For this condition $\xi(t)$ is zero. The addition of a periodic input signal [B sin(ωt)] to the bi-stable system makes it time dependent whose dynamics are govern by (5).

$$\frac{dx(t)}{dt} = -\frac{dU(x)}{dx} + B\sin(\omega t) + \sqrt{D}\xi(t) \quad (5)$$

where, B and ω are the amplitude and frequency of the periodic signal respectively.

SNR expression for dynamic stochastic resonance as derived is given in (6).

$$SNR = \left[\frac{4a}{\sqrt{2}(\sigma_0\sigma_1)^2}\right]\exp\left(-\frac{a}{2{\sigma_0}^2}\right) \quad (6)$$

When we differentiate (6) w.r.t. a and equate to zero then we get $a = 2\sigma_0^2$ and $b < 4a^3/27$. Solving the stochastic differential equation given in (5) after substituting U(x) from (3) and using the stochastic version of Euler-Maruyama's iterative method, the pixel value at n+1th step can be represented in terms of pixel value at nth step, parameters a & b and the input as given in equation (7)

$$x(n+1) = x(n) + \Delta t[ax(n) - bx^3(n) + input(n)] \quad (7)$$

a. DISCRETEWAVELET TRANSFORM

Recently, wavelets have been frequently used in image processing. They are useful for image enhancement, denoising, image super resolution and compression etc. Wavelet transform decomposes a signal into a set of base functions called wavelets. Wavelets and wavelet transform are used to analyse the signal. Wavelet is a wave form with respect to time. Wavelets are obtained from a single prototype wavelet $\psi(t)$ called mother wavelet by using shifting and dilations. DWT is one of the recent types of wavelet transform used in image processing. DWT divides an image into a 4 different sub-bands namely low-low (LL), low-high (LH), high-low (HL) and high-high (HH). LL is lower resolution approximation image, LHHL and HH are vertical, horizontal and diagonal detail components respectively.

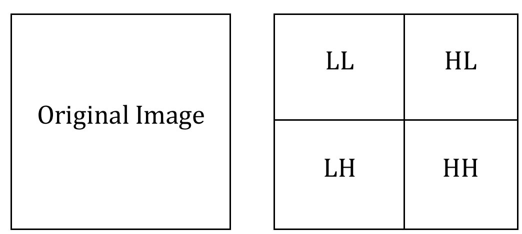


Fig. 2: level-1 wavelet transform for image

The 2-D wavelet decomposition of an image is performed by applying first 1-D DWT along the rows of an image and then the results are decomposed along the columns. In [25, 27] researchers uses an advancement of wavelet theory in image enhancement.

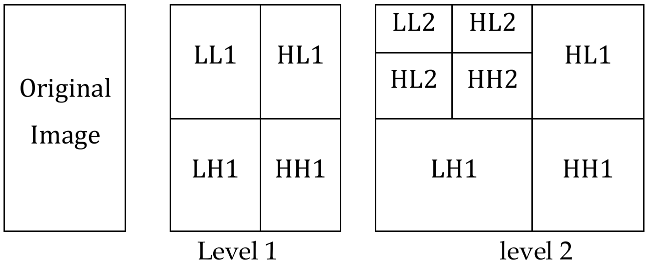


Fig. 3:2 level wavelet transform for 2-D image

b. NOISE

The departure of any ideal signal is referred to as noise. A model of an image is degraded by adding random noise.

$$g(x,y) = f(x,y) + n(x,y)$$

Where, n (x,y) is signal independent additive random noise.

There are different types of noise distributions that are used in image enhancement such as Gaussian, uniform, gamma, poison and slat & pepper noise. In [24] different noise distribution explained for noise-induced enhancement. The Gaussian noise is the most common type of noise and it follows normal distribution and is expressed by probability density function. In this paper, salt & pepper noise is used. It is also known as speckle or impulses. The level of noise is generally expressed by its variance. The mean and variance are important parameters to characterize the noise. Generally mean value show the average brightness of the noise.

4. PROPOSED DYNAMIC STOCHASTIC RESONANCE

The proposed algorithm is quite useful in enhancing the contrast of images and also in denoising the images. In this, a phantom noisy image is created by adding external noise of different intensities, so original image is available for reference. Now, in this algorithm, only internal noise is used which is already present in the noisy image. Then bi-stable parameters a, b and Δt are optimized w.r.t. each other and a number of iterations are performed by an adaptive procedure. In the iterative equation, input(n) = Bsin(ωt) + √Dξ(t) which denotes the sequence of noise and input signal, with the initial condition xo=0. By using the DWT, the noisy image is divided into different sub-bands and then DSR is applied only on the higher frequency sub-bands.

In the proposed algorithm, the sharp edges of higher frequency sub-bands of wavelet transform have been indentified first and then DSR is applied on each pixel of smooth identified area. In other words, the DSR technique applied on a single big image is now applied on a number of small smoothed image areas. This technique is better than the existing DSR algorithm in terms of computational requirement since the DSR is now applied on relatively smaller matrices. Also the time required to perform iterations on redundant pixels is saved. A count of 100 iterations is used for noise variance. The bi-stable parameters are identified only for the approximation coefficients, so which are computed from approximation band and later used in all detailed coefficients.

Steps:

1. Add a external noise of standard-deviation σo to the original image to form a noisy image.
2. Separate the three layers (RGB) of noisy image.
3. Apply discrete wavelet transform on the noisy image.
4. Calculate constants a as a $= 2\sigma_0^2$, b=0.00001 x 4a3/27 and take Δt = 0.01 so that b remains well below (4a3/27).
5. In the higher frequency sub-bands noisy areas with sharp edges are identified.
6. Gaussian low pass filter is applied to smooth out that identified area.
7. For each pixel value x (n) in the identified noisy area of detailed coefficients sub-bands, new pixel value is turned as:
   x (n+1) = x(n) + Δt[ax(n) – bx3(n) + v]
   where,
   v is pixel value of initial image.
   n is the iteration no.
   x(n) is taken as zero at the starting.
8. The iterations are carried out until the difference between the pixel values of 2 consecutive steps are same or within required small tolerance limit. Reconstruct the image by applying inverse wavelet transform by using the original approximation and new formed detail coefficients.

a. PERFORMANCE MATRICES

To gauge the quantity of the proposed DSR-based enhanced image, quantitative parameters Noise Mean Value (NMV), Noise Standard Deviation (NSD), Mean Square Difference (MSD) and Peak to Signal Ratio are used [28].

Noise Mean Value (NMV):- The estimated noise variance is used to determine the amount of smoothing of the image.

$$NMV = \frac{\sum_{i=0}^{N-1} S_i}{N}$$

where, $S_i$are the elements of de-noised signal.

Noise Standard Deviation (NSD):-

$$\sqrt{\frac{\sum_{i=0}^{N-1}(S_i - NMV)^2}{N}}$$

Mean Square Difference (MSD):- It indicates average square difference of the pixels throughout the image between the original images (with speckle).

$$\frac{\sum_{i=0}^{N-1}(S' - S_i)^2}{N}$$

where, S′ are the elements of noisy image.

5. RESULTS

The different outputs are obtained for different varying noise intensities. Figures 4 a) and b) show the original image which is noise free and the enhanced images obtained from different techniques as S2DWT, H2DWT, LPF, DSR and proposed DSR technique for noise variances v=0.01 and v= 0.1 respectively Then the graphs of performance matrices have been drawn using NMV, NSD and MSD for varying noise intensities as shown in Figures 4 c), 4 d) and 4 e)

Fig. 4 a) Image Enhancement by different techniques with variance =0.01

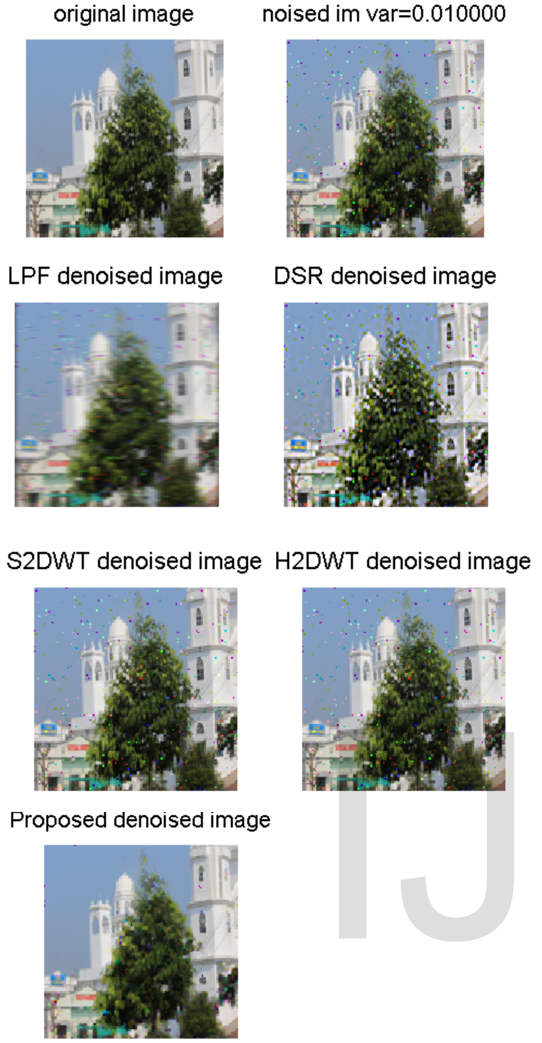
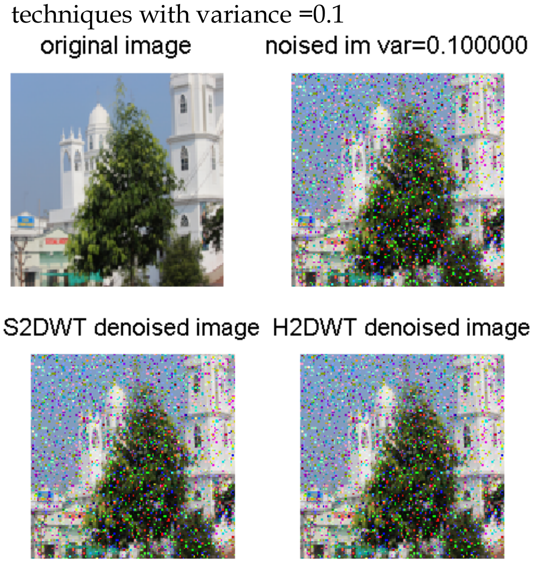
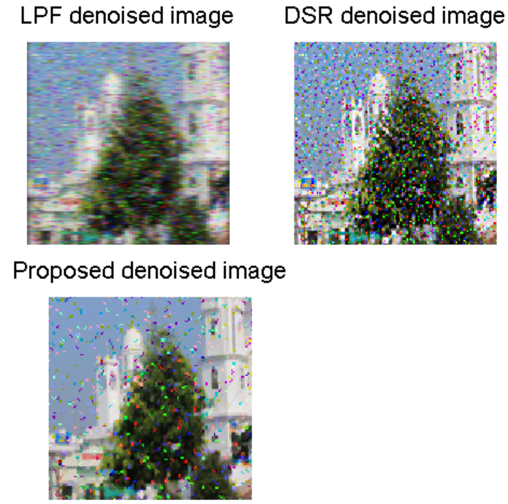


Fig. 4 b) Image Enhancement by different techniques with variance =0.1





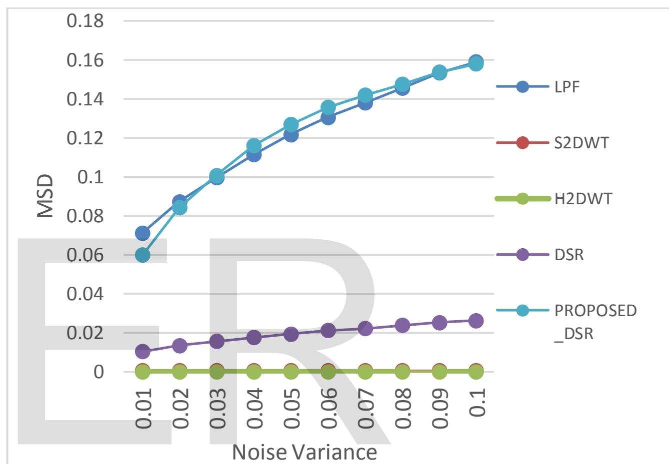


Fig. 5 a) Comparison of Various Techniques used in terms of MSD

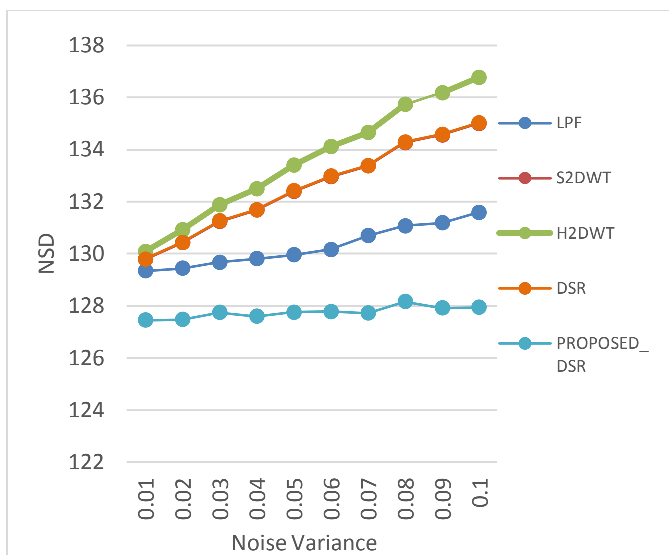


Fig. 5 b) Comparison of Various Techniques used in terms of NSD

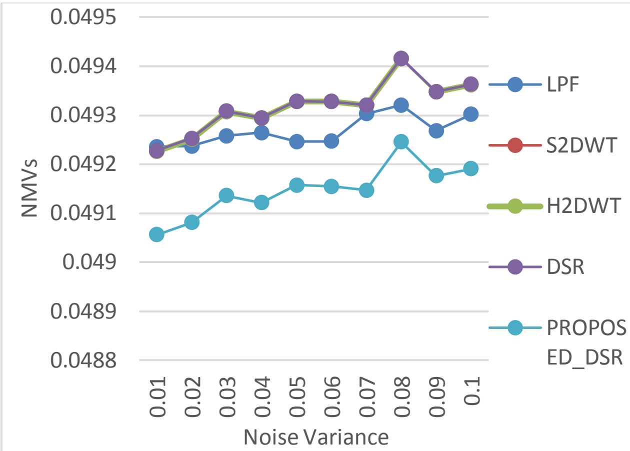


Fig. 5 c) Comparison of Various Techniques used in terms of NMV

Table 1. Performance analysis in terms of MSD of the proposed technique with other techniques

MSD					
Variance	**LPF**	**S2DWT**	**H2DWT**	**DSR**	**Proposed**
0.01	0.071213	0.00434	5.14E-4	0.010355	0.059907
0.02	0.087213	0.00434	5.12E-4	0.013376	0.084085
0.03	0.099579	0.00435	5.12E-4	0.015477	0.100627
0.04	0.111384	0.00435	5.09E-4	0.017502	0.115928
0.05	0.121683	0.00436	5.08E-4	0.019401	0.126687
0.06	0.130465	0.00436	5.15E-4	0.021076	0.135526
0.07	0.137913	0.00437	5.18E-4	0.022133	0.141826
0.08	0.145466	0.00437	5.15E-4	0.02378	0.147369
0.09	0.153354	0.00438	5.12E-4	0.025224	0.15365
0.10	0.158840	0.00438	5.10E-4	0.026288	0.157911

Table **2.** Performance analysis in terms of NSD of the proposed technique with other techniques

NSD					
Variance	**LPF**	**S2DWT**	**H2DWT**	**DSR**	**Proposed**
0.01	129.3476	129.7846	130.0844	129.7969	127.4467
0.02	129.4451	130.4254	130.9127	130.4393	127.4767
0.03	129.6718	131.2388	131.8881	131.2541	127.7465
0.04	129.8121	131.6761	132.4985	131.6929	127.5994
0.05	129.9542	132.3931	133.3929	132.4112	127.7626
0.06	130.1621	132.9538	134.1170	132.9732	127.7838
0.07	130.6902	133.3647	134.6554	133.3852	127.7245
0.08	131.0683	134.2668	135.7198	134.2882	128.1653
0.09	131.1806	134.5559	136.1851	134.5788	127.9144
0.10	131.593	135.0045	136.7631	135.0282	127.9423

Table **3.** Performance analysis in terms of NMV of the proposed technique with other techniques

NMV					
Variance	**LPF**	**S2DWT**	**H2DWT**	**DSR**	**Proposed**
0.01	0.049236	0.049227	0.049227	0.049228	0.049057
0.02	0.049237	0.049251	0.049251	0.049252	0.049081
0.03	0.049258	0.049307	0.049307	0.049308	0.049136
0.04	0.049264	0.049294	0.049294	0.049294	0.049122
0.05	0.049246	0.049328	0.049328	0.049328	0.049157
0.06	0.049247	0.049328	0.049328	0.049328	0.049155
0.07	0.049303	0.049320	0.049320	0.049321	0.049147
0.08	0.049321	0.049416	0.049416	0.049416	0.049245
0.09	0.049268	0.049347	0.049347	0.049348	0.049177
0.10	0.049302	0.049362	0.049362	0.049363	0.049191

6. CONCLUSION

In this paper a modified DSR technique for image enhancement and denoising in wavelet domain is introduced. DSR technique is applied on the noisy image in the form of iterative equation by using varying noise intensities or variance. By adjusting the bi-stable parameters a, b and Δt of DSR remarkable enhancement can be obtained at minimum computational complexity. For coloured & Gray scale images, it gives a better visual perception than exciting enhancement techniques like LPF, S2DWT, H2DWT and DSR in terms of performance metrics like MSD, NSD and NMV.

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