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Contrast Enhancement and Foreground Image Sharpening using Dynamic Stochastic Resonance

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Abstract: In this paper we enhanced poor illuminated low contrast image and sharpen the foreground part using stochastic resonance (SR). Noise generally hinders communication system. But by using SR image, performance is improved by adding noise. At an optimum noise level SNR performance become appreciable. Literally this pixel dynamics concepts adopts particle mechanics following Benzi'sbistable model. Feature is extracted from the foreground content of the image. DSR is a spatial domain approach. DSR is iteratively applied on the modified Value matrix of the transformed HSV image of the original image and the modified value matrix is obtained from the extracted feature of the input image. Optimum output is obtained by computing performance matrices like Relative Perceptual Quality Metric (PQM), Relative Contrast Enhancement Factor (F), Colour enhancement factor (CEF). This technique significant improves contrast, sharpening, colour and perceptual quality.

***Key words**:* double well, bistable system, dynamic stochastic resonance, foreground image.

1. INTRODUCTION

Generally images captured insufficient illumination have very low intensity values resulting difficulty to interpret details present in image. To improve visual perception of dark images we need to enhance contrast. Different types of contrast enhancement techniques are exist in both spatial and transform domain, including gamma correction, low pass filtering, high-pass filtering and most basic and common histogram equalization etc. [1,2] DSR is a different approach.

SR was first experimentally done in [3]. Here authors focused on psychophysics which states that human brain resolves details of an image, corrupted by time varying noise. Interpretation of its quality depends upon temporal characteristics and its noise intensity.

For nonlinear systems, noise can be used amplify weak signals and to increase SNR [6-8].In this paper, we are utilizing SR in spatial domain to enhance dark, low contrast images. Internal noise of image is used for enhancing image contrast. DSR based method can be used for images that are dark, dull looking images, shown in [4]. Low contrast medical images are improved by SR in [5]. Parameter like perceptual quality metric is thoroughly discussed in [9, 10] whose matlab code is available in [12]

Since, most of the image processing software introduce impulse noises, hence our motivation is to sharpen the salient part. Here foreground edges are extracted to sharpen the foreground part of the image. DSR is applied on modified V comprised HSV image.

Remaining paper is arranged as followed. Section II explains DSR concept, section III computes modified value matrix, section IV. explains requisite formulation, section V presents Quantitative

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Performance Parameters, section VI represents proposed algorithm, and section VII entails simulation results.

2. DYNAMIC STOCHASTIC RESONANCE

According to Benzi'sbistable model a particle can reside any of two stable states. i.e.low weak state and high excited state in stable condition. Shifting from low to high state is achieved by increasing temperature. After a certain no of oscillations the particle changes its state depicted in Fig 1.

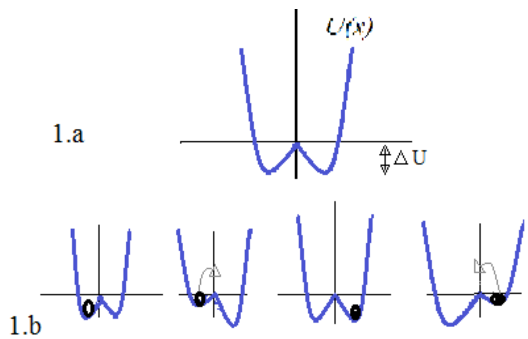

Figure 1 a: Bistable double well potential, Figure 1 b: Particle crossing barrier.

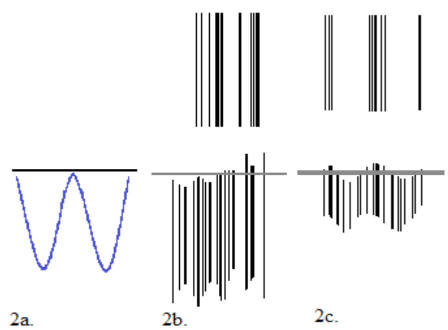

Figure 2a: Sub-threshold signal, Figure 2b: Very high Noise, Figure 2c: Optimum noise

This method is derived from Benzi's double well model, where each pixel is analogous to discrete particle and its intensity values is analogous to kinetic quantity of the motion (Brownian motion) of discrete particles. For DSR mechanism input signal must be subthreshold. Further migration of the pixel value from low to high contrast is achieved by 'induced noise' resonance between image noise and subthreshold signal after few iterations.

In figure 2.a SNR is very low, i.e. Signal magnitude is too low to cross the threshold. In figure 2.b noise is so high, addition of signal and noise is purely dominated by noise. But in figure 2.c optimum amount of noise is added so that signal along with noise crosses threshold and signal is detectable.

To have SR, a system model should have certain attributes like nonlinearity in threshold, a subthreshold signal having low amplitude and additive noise. Weak signal cannot cross the threshold in presence of low noise, having low SNR. Also at large noise intensities the output dontaminates by noise, again giving low SNR value. Therefore at appropriate noise intensities signal crosses threshold with maximum SNR. SR is expressed by Langevin'smotion equation of a particle in double well,

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

The above equation informs particle's motion with 'm' mass in existence of friction. Restoring force is derivative of bistable potential function U(x). If system is supposed to be heavily damped the initial term can be neglected. U(x) presents quartic potential function. a,b are parameters for bistable systems.

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

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

Relation of Langevin's equation with image model is, the inertial term is similar to particle motion changing in double well system which is the frequency of gray level changes in image. Also the negative gradient of U(x) represents the image contrast. $\sqrt{D}\varepsilon(t)$ represents internally or externally added noise function.Adding periodic input signal to (2) makes it time dependent.

$$\frac{dx(t)}{dt} = -\frac{dU(x)}{dx} + B\sin(\omega t) + \sqrt{D}\varepsilon(t) \tag{4}$$

Where B is amplitude and is frequency of added input signal.

$$U(x,t) = U(x) - B\sin(\omega t) = -a\frac{x^2}{2} + b\frac{x^4}{4} - B\sin(\omega t) \tag{5}$$

Simplyfing, $$\frac{dx(t)}{dt} = [ax - x^3] + B\sin(\omega t) + \sqrt{D}\varepsilon(t) \tag{6}$$

Most important descriptor is SNR. $$= \left[\frac{4a}{\sqrt{2(\sigma_0\,\sigma_1)}^2}\right]\exp\left(\frac{-a}{2{\sigma_o}^2}\right) \tag{7}$$

Whereis internal noise standard deviation and $\sigma_1$is for added noise.

3. COMPUTATION OF MODIFIED VALUE VECTOR FOR SHARPENING

By image pre-processing geometry distortions, blurring are corrects and noise is removed. Noise is present in an image due to fault in acquisition, camera temperature etc. And affects pixel values. After filtering a structuring element (SE) is created to perform morphological opening followed by background subtraction to get uniform background for concerned image. Here we used SE of 'square' shape. Now that uniform background is subtracted from the original image. Edges are detected from the subtracted foreground image using 'prewitt' operator and stored in one vector v1 which is multiplied with original value vector derived from HSV transformed original image for sharpening the foreground part.

4. FORMULATION OF DSR FOR IMAGE CONTRAST ENHANCEMENT

To formulate iterative equation for DSR based image enhancement,we consider image in spatial representation as *I(x,y)*, where *I* is pixel value. DSR applied on modified value vector(V) of HSV of *I(x,y).*

$$V(x,y) = \mathbf{DSR}\,[V(x,y)] \tag{8}$$

Euler Maruyama's method converts differential equation to difference equation.

$$\boldsymbol{x(n+1) = x(n) + \Delta t[ax(n) - bx^3(n) + \mathrm{input}]} \tag{9}$$

Here, modified intensity of *I(x,y)* or V matrix replaces input term.

4.1 Selection of Image Enhancement Parameters

4.1.1. Selection of 'a' value:

To maximize SNR, (7) is differentiated with respect to a, then equating with zero,

$$\frac{d(SNR)}{d(a)} = \left[\frac{1}{\sqrt{2(\sigma_0\,\sigma_1)}^2}\right] \exp\left(\frac{-a}{2\sigma^2{}_0}\right) - \left[\frac{a}{\sqrt{2(\sigma_0\,\sigma_1)}^2}\right] \left(\frac{1}{2\sigma^2{}_0}\right) \exp\left(\frac{-a}{2\sigma^2{}_0}\right) = 0 \qquad (10)$$

Maximum SNR value will occur at $a = 2\sigma_o{}^2$. This will yield $a = 2\sigma_o{}^2$ (11)

4.1.2. Selection of 'b' value

For a low contrast image, which is a subthreshold signal parameter b is found bymaking double derivative of $U(x)$. Deriving (5) with respect to *x* gives twice,

$$R = -\frac{dU(x)}{dx} = -ax + bx^3 \qquad (12)$$

$$\frac{dR}{dx} = -a + 3bx^2 = 0 \qquad (13)$$

Which implies $x = \sqrt{(a/3b)}$, putting it in (12) gives,R = $\sqrt{(\frac{4a^3}{27b})}$. The periodic force $Bsin(\omega t)$ should be less than R. normalizing periodic force produces,

$$1 < \sqrt{\frac{4a^3}{27b}} \qquad (14)$$

Hence for weak input signal $b < \left(\frac{4a^3}{27b}\right)$.This will yield, $b = \left(\frac{4a^3}{27b}\right)$ (15)

5. QUANTITATIVE PERFORMANCE PARAMETERS

Since input image is not distortion-free, we can not use mean-square-error (MSE), peak signal to noise ratio (PSNR), structural similarity index measure, quality index etc. Rather we have to use

5.1 Relative contrast enhancement factor (*F*): Which is, $F = Q\_B/Q\_A$ (16)

Where, Q=image contrast quality index, $Q = \frac{\sigma^2}{\mu}$, (17)

μ=mean of image, $\boldsymbol{\sigma}$ =standard deviation of image,$\boldsymbol{Q_A}$=quality index of pre-enhanced image,$\boldsymbol{Q_B}$=quality index of post-enhanced image.

5.2 Perceptual quality metric (PQM):

$$PQM = \alpha + \beta B^{\gamma 1} A^{\gamma 2} Z^{\gamma 3} \qquad (18)$$

Where $\alpha = -245.9, \beta$=261.9, γ1=-0.0240, γ2=0.0160, γ3=0.0064 are obtained by simulating a number of images. JPEG is block DCT based lossy coding technique. Blurring and Blocking artifacts are created during quantization. Blocking effects are due to discontinuity at block boundaries. Denoting test image as$x(m,n)$, calculating differencing signal along horizontal line,

$$d_h(m,n) = x(m,n+1) - x(m,n), n \in [1, N-1] \quad (19)$$

The features are calculated horizontally, Horizontal blockiness is:

$$B_h = \frac{1}{M([\frac{N}{8}-1])} \sum_{i=1}^{M} \sum_{j=1}^{\frac{N}{8}-1} |d_h(i, 8j)| \quad (20)$$

Blockiness parameter B is= $\frac{B_h+B_v}{2}$, where vertical blockiness is B_v. (21)

To find blurring average absolute difference horizontally between in block images is

$$A_h = \frac{1}{7}\left[\frac{8}{M(N-1)} \sum_{i=1}^{M} \sum_{j=1}^{N} |d_h(m,n)| - B_h\right], \quad (22)$$

A_v is average absolute difference vertically. Parameter A becomes: $A = \frac{A_h+A_v}{2}$ (23)

$$Z_h = \frac{1}{M(N-2)} \sum_{i=1}^{M} \sum_{j=1}^{N-2} Z_h(m,n) \quad (24)$$

zero crossing rate horizontally is Z_h, vertically is Z_v, overall it is $Z = \frac{Z_h+Z_v}{2}$ (25)

It is desired to have PQM value of 10.[11]

5.3 Colour enhancement factor(CEF): it is colorfulness of the enhanced image to that of original. Where, colorfulness metric:

$$CM(I) = \sqrt[2]{\sigma_\alpha^2 + \sigma_\beta^2} + 0.3\sqrt[2]{\mu_\alpha^2 + \mu_\beta^2} \quad (26)$$

And $\alpha = R - G, \beta = R + \frac{G}{2} - B$

6. PROPOSED ALGORITHM

Step.1 Image Pre-processing

Once the image is acquired, it is pre-processed to suppress undesired distortions.

i) Image is converted to grey scale to compute it easily.

ii) Noise is removed by smoothing the image using Gaussian mask.

iii) ‘square’ shape structural element(SE) is created and Gaussian smoothed image is first eroded with the SE. then dilated with same SE.

Step.2 Image Feature extraction

The dilated image is first subtracted from the Gaussian smoothed image for background subtraction. The edges of the subtracted image are detected using ‘prewitt’ operator. Converting the class type this edges are stored in one vector.

Step.3 Convert image space from RGB to HSV

Conversion of RGB image or the original image to HSV image space to preserve the implicit color of image and to minimize the computation complexity.

Step.4 compute modified V of HSV image space

Get the *v* vector of the HSV image from step. 3 Using v1 from step.2 perform the following mathematical operation: $V = v + v .* v1$

Step.5 Applying DSR iterative equation

Here, intensity values of an image are changed using DSR iterative equation, for that find a and b values from standard deviation of original image. From (11), (15), $\Delta t = 0.01, a = 2\,\sigma^2{}_0, b = 0.00001 \times {}^{(4a^2)}/_{27}$.

Gray values of image tuned according to DSR equation (9)Where vector from step.4 is substituted to input term.

Step.6 Adaptive Iteration

We will compute new HSV image using previous Hue, Saturation and new Value Vector obtained from step 4. The DSR is applied for each iteration. Performance metrics are calculated at each iteration and checked for optimum values. Iteration continues till F(n)+CEF(n) is maximum with PQM closer to 10. PQM value for better image perception and visualization is defined to be close to the 10 in [11]

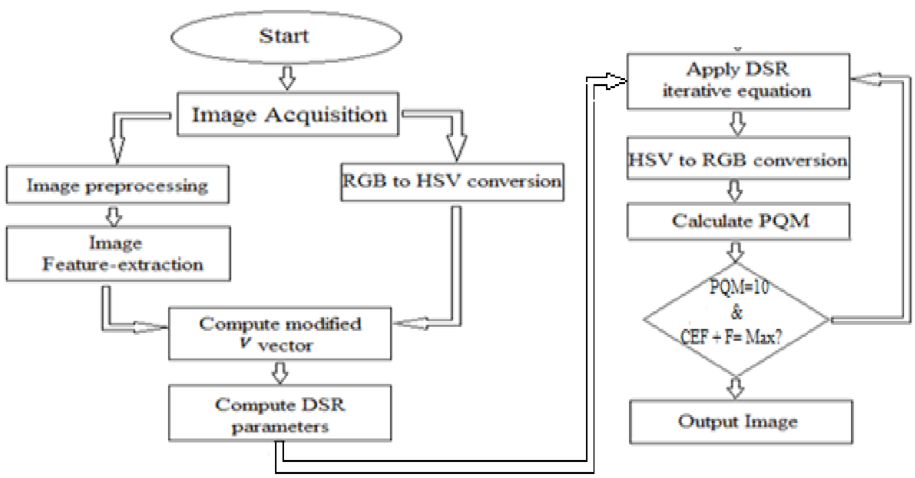

Figure 3: Proposed algorithm

7. SIMULATION RESULT ANALYSIS

Proposed algorithm is tested over 40 random low contrast images. Among which 20 images are natural dark, poor illuminated images (e.g. Fig 7a, 7b) and rest had been made low contrast images by photo editing softwares. (e.g Fig 4a-4d). For most of images, No of iterations required to get optimum result is 11. Here we used MATLAB v2013a software on Windows8.1 64-bit with Intel core i5-3337U CPU @ 1.80 GHzwith 4.00 GB RAM and Graphics card is of Intel HD Graphics 4000.

Figure 4a-4d: Low contrast images. Figure 5a-5d.extracted features Figure 6a-6d: DSR enhanced and foreground sharpened images.

Here foreground objects are extracted first and DSR is applied iteratively. For very dark image like lena, suflower intensity values are distributed widely.

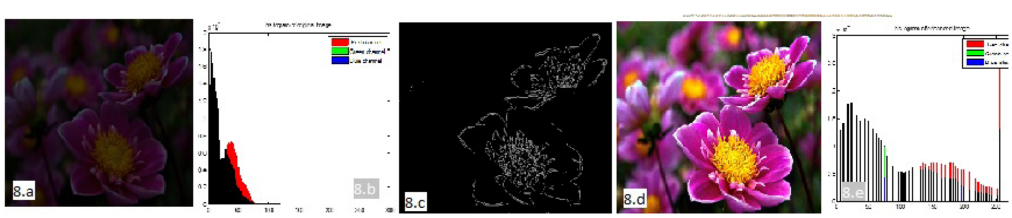

Fig: 8a. Poor illuminated low contrast image, corresponding histogram in Fig. 8b. Featured are extracted in Fig. 8c. DSR enhanced and foreground sharpened image in Fig 8d and it's histogram in Fig 8e.

In fig 8a. Intensity distributions is very narrow, which we can see in their histogram plot at the darker end of intensity scale. As we continue to iterate DSR equation, pixels of sub-threshold image acquire enough energy to cross the threshold like particles get enough energy to move from lower energy state to higher energy state in Double-well. Hence the histogram of the DSR enhanced image is spreaded over the wide dynamic range. Here the two flowers which are closer to the lens i.e. foreground objects are detected from the other flowers of the image which became as a background part and consequently these front two flowers are sharpened more than the others.

Table 1
Quantitative performance parameters and Enhanced mean of Value vector.

Images	*PQM*	*F*	*CEF*	*Mean v*	*Mean V*
Lena(fig 4a)	10.7877	7.1494	4.1744	0.0503	0.0520
sunflower(fig 4b)	10.8259	3.3407	3.3398	0.2646	0.2738
Baboon(fig 4c)	10.9676	8.6094	4.6227	0.0655	0.0677
Fruits(fig 4d)	11.7520	6.2900	4.1203	0.0706	0.0722
Ice cream(fig 7a)	12.7268	2.8382	3.5513	0.1740	0.1795
(fig 7b)	9.4291	3.5766	4.0729	0.1305	0.1371
Lavender (fig 8a)	10.8345	4.1314	4.2606	0.1271	0.1323

From [4] parameters are quite appreciable among existing enhancement techniques. Here we tabulated these by DSR and value vectors before and after pre-processing. It provides significant improvement in contrast enhancement of foreground object.

8. CONCLUSIONS

In this paper low contrast, dull looking image is properly enhanced with sharp edges in foreground which is very useful for images taken in macro mode under poor illumination. DSR concept uses image's internal noise. Selection of parameter's initial value and iteration numbers plays very important role and varies according to the image. This method provides high contrast enhancement factor (F). CEF signifies that colourfulness of enhanced image is higher than the original low contrast image. PQM is also closer to 10, a higher diversion degrades perceptual quality. This DSR based method is useful for both the grey scale as well as colour low contrast images.

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