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Dark Image Enhancement using Dynamic Stochastic Resonance

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Abstract— In this paper, contrast enhancement of dark image using Discrete Cosine Transform (DCT) and Discrete Wavelet Transform (DWT) coefficients is proposed. Then the contrast enhancement is obtained by applying Dynamic Stochastic Resonance (DSR).The goal of dark image enhancement is to clearly visualize the features of the image. Two different coefficients DCTand DWT are used for implementing contrast enhancement respectively. One is applying Discrete Cosine Transform (DCT) and the other is applying Discrete Wavelet Transform (DWT) to the input image respectively. Initially DSR is applied to the DCT coefficients\DWT coefficients. Then the DCT coefficients/DWT coefficients are tuned to certain bistable system parameters and though this image is enhanced. In terms of contrast enhancement Factor(F), Color enhancement factor (CEF) and Perceptual quality metric (PQM), the proposed technique using DWT exhibits better performance than the other enhancement techniques such as conventional contrast enhancement techniques and the contrast enhancement technique using DCT.The important applications of dark image enhancement are fingerprint feature extraction and in satellite images.

Index terms— *Dynamic stochastic resonance, contrast enhancement factor, Color enhancement factor, Perceptual quality metric.*

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1 INTRODUCTION

The objective of image enhancement is to modify images in such a way that the visual content contained in the image is improved for human or machine perception as in [1]. Many images have very low dynamic range of the intensity values due to insufficient illumination and therefore the images are needed to be processed before being displayed.

The enhancement methods are broadly classified into the following two categories in [2] as: Spatial Domain Methods and Frequency Domain Methods. In spatial domain techniques, it is directly deal with the image pixels. The pixel values are manipulated to achieve desired enhancement. In frequency domain methods, the image is first transferred into frequency domain. It means that, the Fourier Transform of the image is computed first. All the enhancement operations are performed on the Fourier transform of the image and then the Inverse Fourier transform is performed to get back the original image. These enhancement methods are performed to modify the image brightness, contrast or the distribution of the grey levels.

The above two enhancement methods can be again classified as direct and indirect enhancement techniques as in [3]. In this paper, we use indirect enhancement technique where the image is enhanced without explicitly defining and measuring image contrast . This technique includes Histogram Equalization (HE) and its variants, basic pixel.

A large number of techniques have been proposed on the enhancement of gray level images in the spatial domain. These methods include histogram equalization, gamma correction and high pass filtering, low pass filtering, homomorphism filtering as in [4], and [5] respectively.

Noise is usually a nuisance which disturbs the system. Recently, a concept of physics called Dynamic Stochastic Resonance (DSR) has been used in image enhancement. Stochastic resonance is a phenomenon in which noise can be used to enhance rather than affecting the system performance.

In this paper, DSR is applied on DCT/DWT coefficients for enhancement of very dark images. This technique optimizes the bistable system parameters and maximizes performance by an iterative procedure. The major objective of this technique is to reduce the computational complexity and storage requirements.

2 RELATED WORK

Choonwoo Ryu, Seong G. Kong and Hakil Kim in [6] proposed a method for enhancing feature extraction for low-quality fingerprint images by adding noise to the original image. In nonlinear signal processing systems, a moderate amount of noise can help to amplify a faint signal while excessive amounts of noise can degrade the signal. In Stochastic Resonance (SR) method, low quality finger print images are taken as input. SR enhancement takes a minimum noise level. So, noise level is chosen to

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be any value. Noise level is then estimated by iterative method using stochastic gradient ascent. The SR enhancement enables feature extraction of low-quality fingerprint images. Feature extractors generate fingerprint features when the input image is of an acceptable quality. If no fingerprint template is generated until the noise parameter reaches a predefined limit the fingerprint image is regarded as a failure in feature extraction. Finger print extraction is not done for damaged fingerprint patterns. The equal error rate is improved from 6.55% to 5.03%.

Rajib Kumar Jha, Rajlaxmi Chouhan and Kiyoharu Aizawa in [7] proposed a dynamic stochastic resonance (DSR) technique for blind watermark extraction in discrete cosine transform (DCT) domain. DSR is an iterative process that tunes the coefficients of the possibly attacked watermarked image so that the effect of noise is suppressed and hidden information is enhanced. Improvement in robustness is achieved due to rearrangement of the distribution of DCT data by an iterative DSR procedure. The noise introduced during attacks is itself utilized in the DSR iterations to suppress the effect of noise on watermark extraction.

Jayanta Mukherjee and Sanjit K.Mitra in [8] proposed a color enhancement technique in the compressed domain. The proposed method is also for the treatment of the chromatic components in addition to luminance components. Proposed algorithm is done by first adjusting the background illumination. Then, the local contrast of the image is preserved. Finally, the colors of the image are preserved. It gives greater performance.i.e; the visual quality of the images is improved.

Ismail A. Humied, Fatma E. Z. Abou – Chadiand and magdy Z.Rashad in [9] proposed a new method is a combination of histogram equalization and Fast Gray-Level Grouping (FGLG). The basic procedure of this method is segmenting the original histogram of a low contrast image into two sub-histograms according to the location of the highest amplitude of the histogram components, and achieving contrast enhancement by equalizing the left segment of the histogram components using (HE) technique and using (FGLG) technique to equalize the right segment of this histogram components. Resultant of this algorithm was implemented and applied to a 46 of low contrast gray scale and colored images such as text, faces and X-ray medical images. The proposed method achieves the best quality through qualitative visual inspection and the image quantitative analysis of Peak Signal-to-Noise Ratio (PSNR), Mean square error (MSE) and Absolute Mean Brightness Error (AMBE) for the used images.

3 Dynamic Stochastic Resonance

Stochastic resonance is a phenomenon that occurs in a threshold measurement system when the appropriate measure of information transfer is maximized in the presence of a non-zero level of stochastic input noise thereby lowering the response threshold.

In order to exhibit SR, a system should possess three basic properties: a non-linearity in terms of threshold, a sub threshold signal like a signal with small amplitude, and a source of additive noise [10]. This phenomenon occurs frequently in bitable systems or in systems with threshold-like behavior. The general behavior of SR mechanism shows that at lower noise intensities the weak signal is unable to cross the threshold, thus giving a very low SNR.

3.1 Mathematical formulation of DSR for Contrast Enhancement

A classic one-dimensional nonlinear dynamic system that exhibits stochastic resonance is modeled with the help of Langevin equation of motion as in [10] and [11] given by (1) as

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

Where $U(x)$ is a bistable potential given in (2).D is the noise variance and $\xi(t)$ is the noise.

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

Here a and b are positive bistable double-well parameters. The double-well system is stable as shown in (3) separated by a barrier of height is shown in (4) when the $\xi(t)$ is zero. Addition of a periodic input signal *[B sin (ωt)]* to the bistable system makes it time-dependent whose dynamics are given by (5).

$$x_m = \pm\sqrt{\frac{a}{b}} \quad (3)$$

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

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

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

By substituting (2) in (5) and on solving we get stochastic version of Euler-Maruyama's iterative discretized method which is shown in (6).

$$x(n+1) = x(n) + \Delta t[ax(n) - bx^3(n) + input(n)] \quad (6)$$

Here that $Input = B\sin(\omega t) + \sqrt{D}\xi(t)$ denotes the sequence of input and noise, with the initial condition being x(0) = 0.This denotion can be done keeping in view that the low contrast image is a noisy image containing internal noise due to lack of illumination.

The objective is to add stochastic fluctuation or noise to the pixel value of the weak signal state so that the pixel particle is activated, jumps over the detector threshold and transits to strong signal state or enhanced state.

3.2 DSR in DCT domain

The histogram of a low contrast/dark image as well as of its DCT transformed coefficient distribution is observed to be of low spread. Squared magnitude of the coefficients imply energy, a low-variance distribution implies that the energy distribution is concentrated in only certain areas, confirming that the image in question is of low contrast.

Now if DSR is applied to these DCT coefficients, its variance is observed to increase with iterations. This is because the coefficients are being tuned by certain bistable system parameters.

The sum of the squares of the normalized AC coefficients provides the variance of the image. Hence, any change in the DC component does not have any bearing on its standard deviation. So under scaling or modification of the DCT coefficients, the mean and standard deviation of the processed image become some multiple of original mean and standard deviation respectively. The contrast of the processed image becomes proportionally certain multiple of that of the original image.

3.3 DSR in Discrete Wavelet Transform

The 2-D Discrete Wavelet Transform (DWT) separates an image into a lower resolution approximation image (LL) as well as horizontal (HL), vertical (LH) and diagonal (HH) detail components. The process can then be repeated to compute multiple "scale" wavelet decomposition. Wavelets are obtained from a single prototype wavelet $\psi(t)$ called mother wavelet by dilations and shifting. One of the many advantages over the wavelet transform is that it is believed to be more accurately model aspects of the HVS as compared to the FFT. In this paper, the nature of DWT coefficients is explored and their behavior to improve contrast of a dark image is discussed.

3.4 Quantitative Performance Metric

The following parameters are used for measuring the performance of the proposed DSR method and the other conventional methods.

- *Metric of contrast enhancement (F)*: Metric of contrast enhancement (F) is based on global variance and mean of original and enhanced images.

Image quality index *Q* has been used such that

$$Q = \sigma^2 / \mu \qquad (7)$$

Here σ and μ are respectively the standard deviation and mean of the image.

Contrast enhancement factor (F) is computed as the ratio of values of Quality index post-enhancement and pre-enhancement.

$$F = Q_A / Q_B \qquad (8)$$

- *Color Enhancement Factor (CEF)* CEF is used to observe the quality in terms of colorfulness in [8]. Let the red green and blue components of an image be denoted by R, G, and B, respectively. Let $\alpha = R - G$ and $\beta = \left(\frac{R+G}{2}\right) - B$, then the colorfulness of the image is defined as,

$$CM = \sqrt{\sigma_\alpha^2 + \sigma_\beta^2} + 0.3\sqrt{\mu_\alpha^2 + \mu_\beta^2}$$

Where, σ_α and σ_β are standard deviations of α and β respectively. Similarly, μ_α and μ_β are their means.

Color enhancement factor is computed as the ratio of CMs between the enhanced image and its original image.

- *Perceptual Quality Metric (PQM),* PQM is used in the evaluation of perceptual quality as given in [8] and [12].

Here for good perceptual quality PQM should be close to 10. For good color and contrast enhancement, respective values CEF and F should be greater than 1.

4 PROPOSED MODEL

The proposed algorithm performs contrast enhancement on colored images by two techniques. One is by applying Discrete Cosine Transform (DCT) and the other is by applying Discrete Wavelet Transform (DWT).The proposed technique significantly enhances the image contrast and color information while ascertaining good perceptual quality. Fig. 1 shows the block diagram of the image enhancement technique using DCT and Fig. 2 shows the block diagram of the image enhancement technique using DWT.

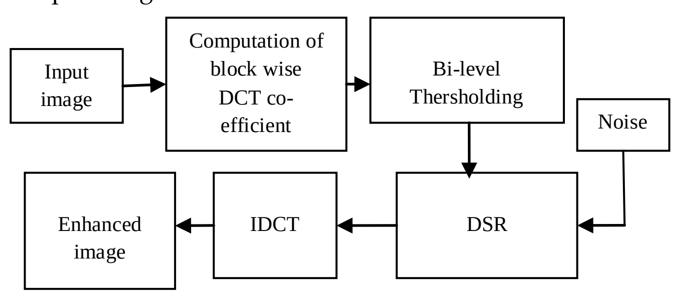

Fig. 1. Contrast Enhancement using DCT and DSR

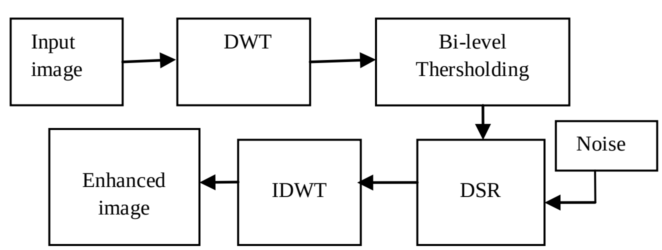

Fig. 2. Contrast Enhancement using DWT and DSR

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4.1 DCT Computation

First the input image is partitioned into 8x8 blocks. Block-wise Discrete Cosine Transform is computed. Standard deviation of each block is calculated. The image can be modified or enhanced in successive steps: If the standard deviation of a block is less than its entropy, then the block is subdivided into blocks of size 4×4 and so on else Bi-level Thersholding can be applied to that block.

4.2 Discrete Wavelet Transform

To compute 2-level DWT decomposition of the input dark image and so DWT co-efficient are obtained

4.3 Bi-Level threshold

In bi-level Thersholding, image is segmented into two different regions. A threshold T is chosen. The pixels with gray values greater than T are classified as object pixels and the other pixel with gray values lesser than T are classified as background pixels.

4.4 Dynamic Stochastic Resonance

Noise-induced DSR is applied to the DCT/DWT coefficients of the dark area given by (6). Bistable parameters are assumed for every intrusion of DSR mechanism given in (10)-(12).

$$a = 2\sigma^2 \tag{10}$$

Where σ is standard deviation of DCT coefficient block set

$$b = 0.0001 \times \frac{4a^3}{27} \tag{11}$$

And

$$\Delta t = 0.001 \tag{12}$$

4.5 Inverse DCT Transform

Inverse DCT/DWT transformation is performed and performances metrics F, CEF and PQM are computed for each iteration of DSR Mechanism. The Number of iterations preformed is upto an iteration count where the metric value F (n) +CEF (n) becomes maximum and starts decreasing along with constraint that PQM is in the vicinity of value 10.

5 Experimental Results

Results obtained using proposed optimization based DCT/DWT-based DSR technique on very dark grayscale and colored images have been shown in Fig. 2. The different formats like tiff , png and jpeg of input images with a dimension of 256 x 256 is enhanced. Proposed DSR-DWT technique is compared with CLAHE existing techniques.

TABLE I. Colour Image(Dark Bright)

	F	CEF	PQM
DSR-DCT	1.86	10.12	1.92
CLAHE	0.76	10.11	1.12

Fig. 3. For Colour image a) Input image b) Enhanced image using proposed DSR-DCT c) Enhanced image using CLAHE d) Enhanced image using proposed DSR-DWT

Fig. 4. For Grayscale image a) Input image b) Enhanced image using proposed DSR-DCT c) Enhanced image using CLAHE d) Enhanced image using proposed DSR-DWT

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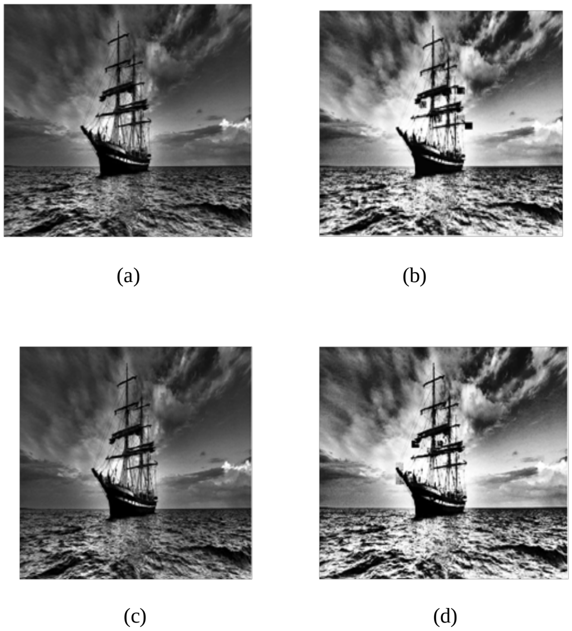

Fig. 5. For Colour image a) Input image b) Enhanced image using proposed DSR-DCT c) Enhanced image using CLAHE output image d) Enhanced image using proposed DSR-DWT

5.1 Comparison with other technique

The response of the proposed technique on two images in comparison with CLAHE [13] has been shown in Fig. 3 and Fig. 4.In the output obtained from existing enhancement technique the brighter portions are observed to be brightened beyond sensible enhancement and there is loss of information in those areas.

One of the most important properties of the proposed DSR-based technique is the enhancement of very dark images. The values are still very dark gray (almost zero) can be modified to a significant increase in image detail. This leads to a very large value of F and the CEF. This property was not observed in other techniques.

The output values are shown in Table I. These are the values of the DCT-DSR/DWT-DSR which reaches more contrast enhancement value (F) for all types of images. The DSR-based DWT technique is found to give remarkably high optimum maximal trade-off value of all performance metrics.

6 Conclusion

In this paper a noise-induced dynamic SR-based contrast enhancement was investigated. The iterative process on noisy coefficients enhances the image energy by making a transition into another state. It is an automatic process that not only adjusts background illumination, but also improves the contrast while implicitly preserving and enhancing color information. Therefore, the proposed DWT-based DSR technique gives remarkable performance over the existing image enhancement techniques in terms of Contrast enhancement Factor(F),Color Enhancement Factor (CEF) and Perceptual Quality Metric (PQM).

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