IMPROVEMENT OF IMAGE ENHANCEMENT, SEGMENTATION AND WATERMARK DETECTION USING STOCHASTIC RESONANCE

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CHAPTER 1

Introduction

1.1 Background

Usually when we speak about *noise*, it means something which worsens the performance of a system. Dictionary [1] says that noise is a disturbance, especially a random and persistent disturbance that reduces the clarity of a signal and so limits system performance. Indeed, we all suffer from the background noise in TV and radio receivers. Engineers always want to screen it out. Presence of such noise is a part of our real life and cannot be neglected or completely eliminated. Interestingly a number of scientific studies carried out since last few decades have shown the good side of noise. A number of natural phenomenon can be explained if the presence of noise is taken into account (e.g. ice ages) [2]. Experiments were also carried out to study the effect of addition of noise to system performance and human perception of signals. These systems include audio compact discs [3], analog to digital devices [4], video images [5], schemes for visual perception [6, 7], and cochlear implant [8, 9]. The aim of this thesis is to develop improved image processing algorithms aided by addition of noise.

The term stochastic resonance was first used in the context of noise enhanced signal processing in 1981 by Benzi *et al.* [10, 11, 12] wherein they addressed the problem of periodic recurrence of Earth ice ages. They used the time-scale matching condition for stochastic resonance, i.e., the average waiting time between two noise-induced inter-well transition which is comparable with half the period of the periodic force for double-well potential.

Stochastic Resonance (SR) is characterized by response of a system to noise. The signal-to-noise ratio (SNR) rises sharply to a maximum value, then gradually decreases for higher noise intensities, as noise is added to a system. In case of stochastic resonance, *resonance* is induced by noise intensity, unlike in case of resonance where it is induced by frequency.

SR phenomenon was also reported by Fauve *et al.* [13] in 1983. They studied the noise dependence of the spectral line of an ac-driven Schmitt trigger. Schmitt trigger circuit was used to demonstrate the effect of SR and it was observed that it is based on bistability. Six years later, SR phenomenon was observed in a bidirectional ring laser, where deliberate addition of noise is shown to lead to an improved output signal-to-noise ratio [14, 15, 16]. Both the Schmitt trigger circuit and the bidirectional ring laser are based on bistable systems. So, bistability was thought to be the necessary condition for stochastic resonance [15].

The first important milestone in the mid nineties was investigation of SR in neural and excitable systems. Prior to this, SR was only observed in bistable systems. The second important milestone was the extension of SR from periodic to aperiodic driving signals. Further extensions of initial and expansion periods include analysis of different types of noise other than the standard additive white Gaussian noise [19], multiplicative noise [17] to colored noise [18].

In late nineties and early two thousand a lot of research on SR was reported. Other developments in more recent years include: analysis of SR in discrete time rather than continuous time systems [20], controlling of stochastic resonance [21, 22], detection of signal using SR [23, 24, 25, 26, 27, 28] and study of adaptive and robust SR in noisy neurons and threshold neurons [29, 30, 31].

SR phenomenon in bistable system is known to exist for more than 75 years. According to Peter Debye [32] the dielectric properties of polar molecules in a solid, effectively shows SR behavior. The formula for SNR was not derived, and there was no comment about optimized measure using non-zero noise intensity. More recently, Kalmykov *et al.* [33] pointed out that another work of Debye can be related to SR, stating that it is possible to generalize the Debye model of relaxation over a potential barrier and to estimate the effect of anomalous relaxation on the SR effect.

Researchers and scientists have already applied stochastic resonance in image processing applications, such as edge detection [34, 35], image enhancement [36, 37, 38], image de-noising [39, 40], image segmentation [41] and watermark detection [42, 43]. Our research work is devoted to the study of SR phenomenon in image applications such as: enhancement of approximately dark images, segmentation of noisy, blurred images under different brightness levels, detection of watermark from the distorted watermarked images and detection of logo from distorted watermarked images.

1.2 Motivation

Most of the images we obtain in real life situation are contaminated with noise. Filtering techniques for noise removal distort the image content. Hence the motivation behind this research work is to add controlled amount of noise for enhancement of image content instead of trying to remove noise by filtering operation. This technique of noise addition for signal enhancement is at the heart of stochastic resonance (SR) and has been successfully applied in various image processing applications such as edge or line detection [34, 35], image enhancement [36, 37, 38], image segmentation [41] and signal detection [42, 43].

Enhancement of very low contrast images without any artifact is a challenging task. The existing techniques [44] enhances the noise while enhancing the image. So, we need to develop a new SR based contrast enhancement technique which can enhance very low contrast images without any blocking or spot kinds of artifacts.

In image processing area, not a single algorithm exists which can properly segment noisy, blurred and varying brightness images. Color thresholding and a newly developed SR-extended segmentation [41] provide simple and fast technique for image segmentation. The color thresholding method is sensitive to the color of the illuminating light and other noise effect in images. SR-extended segmentation is tested to a color image with one object where the input image has high contrast. When this algorithm is tested on multi-object multi-colored images, the edge accuracy of segmentation results are not appriciable. Therefore, in order to get proper segmentation of noisy, blurred and varying brightness images a new method is to be developed. The new method can properly segment the image.

Data authentication is a challenging task among signal processing community. Watermarking provides the authentication of data. The existing watermark detection techniques [45, 46] are not able to authenticate data convincingly when watermarked image is corrupted by signal processing attacks like addition of salt and pepper noise, Gaussian noise, random noise etc. New techniques need to be developed to improve data authentication.

The initial work for data authentication is based on statistical techniques [45, 46]. Data authentication can also be achieved using logo watermarking which is easy to convince non-technical arbitrator. The existing logo detection method [47] is not able to extract the original logo from the corrupted watermarked image. Therefore, a novel method is to be developed which can provide original logo from the corrupted watermarked images.

1.3 Problem Definition

As stated in the previous section new techniques are to be developed for image processing applications where existing techniques fail to provide satisfactory result. In view of the importance of SR in image processing applications, we formally state the problems undertaken in the thesis work as follows.

- Study the analytical and simulation performance of non-linear, non-dynamical SR phenomenon for enhancement of low contrast images. In order to improve the enhancement performance of very low contrast images, two enhancement methods have been proposed. The first method is based on non-dynamical SR phenomenon where a new threshold expression is derived. The second method of enhancement is based on probability of goodness of the noise added very low contrast image. In this method optimal noise standard deviation expression is derived.

- Study the analytical and simulation performance of suprathreshold stochastic resonance (SSR) technique for color image segmentation. Our algorithm is tested on different noisy images having varying brightness using different distribution of noises to make the algorithm robust. Gaussian and Uniform noise distributions are used for color noisy image segmentation.

- Application of SSR for robust watermark detection from watermarked images has been studied so that authenticity of the watermarked image can be confirmed. Improvement of the detector response for Gaussian and Uniform noise distribution in the presence of different attacks is discussed. Using these distributions in watermark detection and obtaining positive detector response also shows the robustness of the SSR phenomenon.

- Dynamic stochastic resonance for detection of original logo from the distorted watermarked image is studied. Improvement in detection of logo from the distorted watermarked image using DWT transform with SSR and combined DWT and DCT transform with SSR is discussed.

This thesis aims to meet above stated objectives. The complete research work is presented in four main chapters (excluding Introduction and Conclusions).

1.4 Stochastic Resonance

The word *noise* in ordinary consciousness is associated with the term *hindrance*. It was traditionally believed that the presence of noise can only make the system worse. However, recent studies have convincingly shown that in non-linear systems, noise can induce more ordered regimes, which cause the amplification of weak signals and increase the signal-to-noise ratio. In other words, noise can play a constructive role in enhancing weak signals. Stochastic resonance is one of the most shining and relatively simple examples of this type of nonlinear systems under the influence of noise. More technically, SR occurs if the SNR, power spectral density (PSD), input/output correlation have a well marked maximum at a certain noise level. This concept was extensively studied and comprehensively reviewed by Namara *et al.* and Gammaitoni *et al.* [15, 21].

In order to exhibit SR, a system should have three basic properties: a non-linearity in terms of barrier or threshold, sub-threshold signals for example signals with small amplitude and a source of additive noise. It occurs frequently in bistable systems or in systems with threshold like behavior. The general behavior of SR mechanism shows that at lower noise intensities, the weak signal does not cross the threshold, so very less SNR. For large noise intensities, the output is dominated by the noise, also leading to a low SNR. But, for moderate noise intensities, the noise allows the signal to cross threshold giving maximum SNR. Thus, a plot of SNR as a function of noise intensity shows a peak at an optimum noise level.

1.4.1 Stochastic Resonance-Classification

The concept of stochastic resonance phenomenon is broadly classified in two categories. First, it is a non-linear non-dynamic phenomenon and second, it is a non-linear dynamic phenomenon. However, recently a new form of stochastic resonance is investigated by Stocks in 2000 [49], called *suprathreshold stochastic resonance.* These concepts are explained below.

Non-linear Non-dynamic Stochastic Resonance

The general block diagram of non-linear non-dynamic stochastic resonance phenomenon is shown in Fig. 1.1. It consists of input signal, random noise and threshold. Moss *et al.* and Jung *et al.* [50, 51] described non-linear non-dynamic SR phenomenon, and set a rule which can be seen in Fig. 1.2.

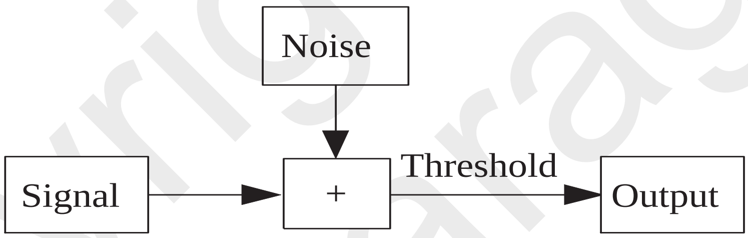
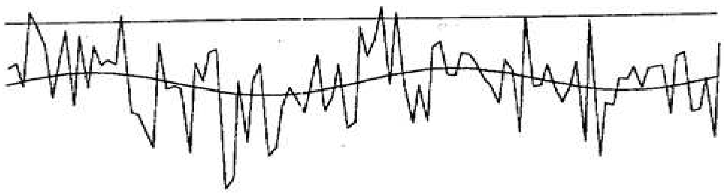


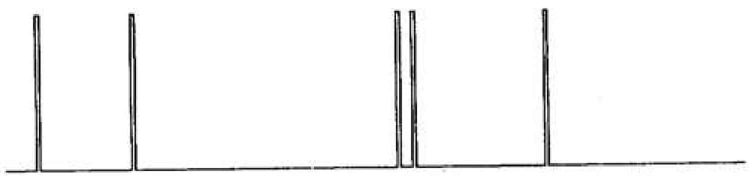
Figure 1.1: Block diagram of non-dynamic stochastic resonance.

The rule is the following: whenever sum of signal and noise crosses the threshold a rectangular pulse is obtained as shown in Fig. 1.2a and 1.2b respectively. The pulse indicates the unidirectional threshold crossing of the combination of signal and noise. This type of non-dynamic SR is called threshold based SR. The power spectrum of rectangular pulse train is a sinc function. They [50, 51] derived an expression for SNR in a threshold based SR system as discussed below.

There are two major assumptions for deriving SNR for non-dynamic system. (i) signal frequency $\omega \ll \langle \upsilon \rangle$, where $\langle \upsilon \rangle$ is the mean threshold crossing rate of Gaussian noise, and (ii) the width of the pulses τ is narrow, i.e., $\tau \ll \langle \upsilon \rangle^{-1}$. The theory of non-dynamic SR begins with a classical formula given by Rice [52], for mean threshold crossing rate of Gaussian noise with cut off frequency f_0 as given in eq. 1.1



(a) Sub-threshold signal ($Bsin\omega t$), threshold (straight line) and random noise



(b) A rectangular pulses which mark the threshold crossing of signal and noise

Figure 1.2: Threshold realization of stochastic resonance.

$$\langle v \rangle = exp\left[-\frac{\Delta^2}{2\sigma^2}\right]\sqrt{\frac{\int_0^\infty f^2 S(f)df}{\int_0^\infty S(f)df}} \tag{1.1}$$

In eq. 1.1, Δ is the threshold, σ is the standard deviation of noise and $S(f)$ is the power spectral density of Gaussian noise. The individual threshold crossing event is marked by a small rectangular pulse of width τ and height A. Under the above mentioned assumptions the power spectrum of the pulse train corresponding to Gaussian noise is defined by the Campbell's pulse noise theorem [50, 53] which is given by.

$$P_n(f) \cong \frac{1}{2}A^2\tau^2\langle v \rangle = \frac{1}{2}A^2\tau^2\frac{f_0}{\sqrt{3}}exp(-\frac{\Delta^2}{2\sigma^2}) \tag{1.2}$$

This is the noise spectra at low frequency or no frequency modulation. So, the mean amplitude of the random pulse train is given by

$$\langle V \rangle = [A\tau\langle v \rangle] = \left[A\tau\frac{f_0}{\sqrt{3}}\right] exp\left(-\frac{\Delta^2}{2\sigma^2}\right) \tag{1.3}$$

The pulse sequence is generated in the threshold based system as the sum of Gaussian noise and sinusoidal signal $B\sin(\omega t)$ of frequency ω crosses the threshold Δ. The output signal to noise ratio as derived in [50] is given below.

$$SNR = 10log\left[\frac{2f_0\Delta_0^2 B^2}{\sigma^4\sqrt{3}} exp\left(-\frac{\Delta_0^2}{2\sigma^2}\right)\right] \tag{1.4}$$

where $\Delta = \Delta_0 + Bsin(\omega t)$

Non-linear Dynamic Stochastic Resonance

A classic one-dimensional nonlinear dynamic system that exhibits stochastic resonance is modeled with the help of Langevin equation of motion given in [54] in the form of eq. 1.5 given below.

$$\frac{dx(t)}{dt} = -\frac{dU(x)}{dx} + \sqrt{D}\xi(t) \tag{1.5}$$

where $U(x)$ is a bistable potential given in eq. 1.6. D is the noise variance and $\xi(t)$ is the noise.

$$U(x) = -a\frac{x^2}{2} + b\frac{x^4}{4} \tag{1.6}$$

Here, a and b are the bistable double well parameters which are positive. The double well system is stable at $x_m = \pm\sqrt{\frac{a}{b}}$ separated by a barrier of height $\Delta U = \frac{a^2}{4b}$ when the $\xi(t)$ is zero.

Addition of a periodic input signal $[B\sin(\omega t)]$ to the bistable system makes it time dependent and the dynamics is governed by eq. 1.7.

$$\frac{dx(t)}{dt} = -\frac{dU(x)}{dx} + B\sin(\omega t) + \sqrt{D}\xi(t) \tag{1.7}$$

where B and ω are the amplitude and frequency of the periodic signal respectively. It is assumed that the signal amplitude is small enough so that in the absence of noise it is insufficient to force a particle to move from one well to another. Substituting $U(x)$ from eq. 1.6 into eq. 1.7.

$$\frac{dx(t)}{dt} = \left[ax - bx^3\right] + B\sin(\omega t) + \sqrt{D}\xi(t) \tag{1.8}$$

In the absence of periodic force the particle fluctuates around its local stable states. The rate of transition of particles (r_k) between the potential wells under the noise-driven switching is given by Kramer's rate [54] as in eq.1.9.

$$r_k = \frac{a}{\sqrt{2}\pi} exp\left[-\frac{2\Delta U}{D}\right] \tag{1.9}$$

When a weak periodic force is applied to the unit mass particle in the potential well, noise-driven switching between the potential wells takes place and synchronized with the average waiting time, $T_k(D) = \frac{1}{r_k}$, between two noise-driven inter-well transitions that satisfies the time-scale matching between signal frequency ω and the residence times of the particle in each well [21]. That is

$$2T_k(D) = T_\omega \tag{1.10}$$

where T_ω is the period of the periodic force.

The most common quantifier of stochastic resonance is signal-to-noise ratio. For a symmetric bistable system, SNR is obtained as [21].

$$SNR = \pi\left(\frac{Bx_m}{D}\right)^2 r_k \tag{1.11}$$

Substituting the value of r_k from eq. 1.9 to eq. 1.11 we get

$$SNR = \left[\frac{a}{\sqrt{2}\pi}\pi\left(\frac{Bx_m}{D}\right)^2\right] exp\left(-\frac{a}{2\sigma_0^2}\right) \tag{1.12}$$

The SNR expression for dynamic stochastic resonance as derived in [34, 53] is given below.

$$SNR = \left[\frac{4a}{\sqrt{2}(\sigma_0\sigma_1)^2}\right] exp\left(-\frac{a}{2\sigma_0^2}\right) \tag{1.13}$$

Here σ_1 is the standard deviation of the added noise in the stochastic resonance based system and σ_0 is the internal noise standard deviation of the original bistable system.

Suprathreshold Stochastic Resonance

Suprathreshold stochastic resonance (SSR) phenomenon is a form of SR phenomenon that occurs in arrays of identical threshold devices subjected to independent and identically distributed additive noise. In such arrays, SR occurs regardless of whether the signal is subthreshold or not, hence the name *suprathreshold SR*. The block diagram of a SSR phenomenon is shown in Fig. 1.3. The SSR phenomenon shows that this effect is maximized when all threshold value is taken as the signal mean [55]. A more general case of SSR where the thresholds are not identical is described in [56]. Therefore, to optimize the performance of the threshold devices thresholds are selected accordingly. The SSR phenomenon is quite general and is not restricted to any particular type of signal or noise distribution.

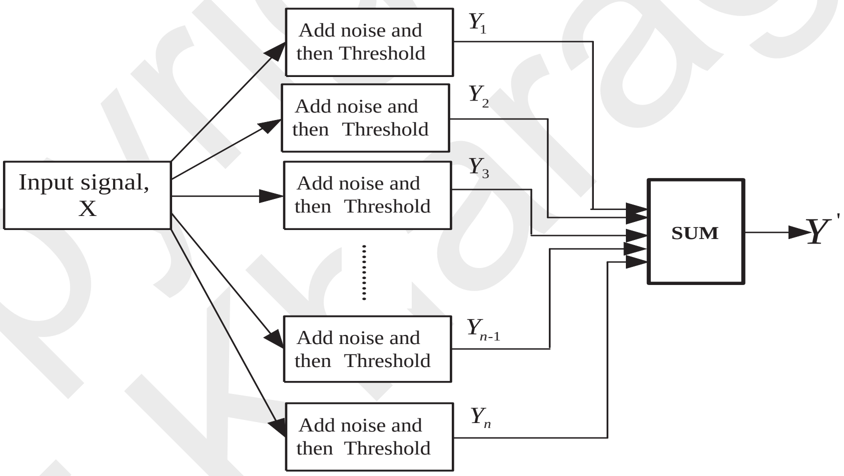


Figure 1.3: Block diagram of SSR phenomenon.

Fig. 1.3 consists of n threshold devices. The i^{th} device in the system is subject to additive noise, (ξ_i). In each individual input signal, X, noise ξ_i, is added. The signal, Y_i, is unity if the sum of signal, X, and noise ξ_i is greater than the threshold Δ (mean of the signal). The output signal is zero otherwise. The thresholded signals Y_i, are summed to obtain the output, Y' which is the result of SSR phenomenon.

1.5 SR Applications in Image Processing

Stochastic resonance phenomenon finds applications in many image processing tasks such as image enhancement, image segmentation, data and image detection etc. A brief review of reported literature is given below.

1.5.1 Image Enhancement Application

Most of the denoising algorithms suppress the noise from the signal. The noise is usually thought to be a nuisance which disturbs the system. Stochastic resonance, on contrary, is a phenomenon in which noise can be used to enhance rather than *hinder* the system performance. The first experimental work on visualization of stochastic resonance was reported in [57]. Recently some of the works on application of stochastic resonance for image processing that have been reported in literature are (a) edge or line detection [34, 35] (b) image enhancement [36, 37, 38], (c) image segmentation [41] and signal detection [42, 43].

First experiment of stochastic resonance for image visualization was reported in 1997 by Simonotto *et al.* [57]. They reported the outcome of a psychophysics experiment which showed that the human brain can interpret details present in an image contaminated with time varying noise and the perceived image quality is determined by the noise intensity and its temporal characteristics.

In 2000 Piana *et al.* [58] described two experiments concerning the visual perception of noisy letters. The first experiment found an optimal noise level at which the letter is recognized for a minimum threshold contrast [57]. In the second experiment, they demonstrated that a dramatically increased ability of the visual system in letter recognition occurs in an extremely narrow range of noise intensity.

Stochastic resonance was used for visualization of noisy images by Marks *et al.* [59] in 2002. They have shown that the multiple realization of the stochastic resonance phenomenon on noisy images, averaged together to form a composite image converges to the original image.

Qinghua *et al.* have used SR phenomenon for image enhancement in 2003. They have applied SR for image enhancement of low contrast sonar images [36]. In this work, they have reported the image enhancement technique which showed that an additional amount of noise besides the noise of the image itself would be helpful to enhance low contrast images.

Theoretical analysis of parametric stochastic resonance for two dimensional case is developed by Xu *et al.* [60]. The two-dimensional parameter-tuning stochastic resonance provides an innovative and promising approach for image processing applications such as enhancement, segmentation etc.

In 2007 Peng *et al.* [61] reported a novel preprocessing approach to improve the low contrast medical image using Stochastic Resonance. The enhancement is improved by adding some suitable noise to the input image. Traditionally considered as a nuisance, noise can sometimes play a constructive role in image processing. Stochastic resonance is one such nonlinear phenomenon where the output signals of some nonlinear systems can be amplified by adding noise to the input.

Study of 2-D image processing by means of bistable stochastic resonance (BSR) is discussed by Zhang *et al.* [62] in 2008. They reported that improvement in the image quality, peak signal-to-noise-ratio (PSNR) by tuning the system parameters is possible. Although BSR can change the images histogram and generally deteriorate the image quality. The example of a noise-polluted image processing using BSR proves the Zhang *et al.* method.

Stochastic resonance (SR) based wavelet transform for the enhancement of unclear diagnostic ultrasound images is reported by Rallabandi in 2008 [38]. This method enhances the edges more clearly and it can simultaneously operate both as an enhancement and a noise-reduction process.

Yang *et al.* [63] developed an elementary theory of two-dimensional (2D) parameter-induced stochastic resonance (PSR) for nonlinear image processing in 2009. That is, the concept of PSR from the one-dimensional (1D) case to the (2D) case. In order to tackle the application of SR in image processing, where adding noise may not be an easy task. PSR based method provides a different, but promising perspective for applying SR phenomenon to nonlinear image processing such as denoising, segmentation etc.

1.5.2 Image Segmentation Application

A new scheme for color image segmentation using stochastic resonance is reported by Janpaiboon *et al.* [41] in 2006. It was shown that the addition of a small amount of noise improves the segmentation accuracy of noisy colored images.

In 2007 Peng *et al.* [61] used SR for segmentation of mammogram mass images. At first, level set evolution (without re-initialization) (LSEWRI) method [64] is employed to do the input mammogram mass images for segmentation and then use the SR phenomenon to further improve segmentation performance. This procedure is iterated 300 times to achieve a correct segmented image.

1.5.3 Image Detection Application

Image processing has been widely used in different areas, such as diagnosing tumors in medical images, detecting cancerous cell in mammogram images, detecting and identifying hostile targets in military images etc. For the images corrupted by noise, most of the de-noising algorithm will try to remove or suppress the noise from the noisy images, because the noise is usually thought to be nuisance. Here noise is used for detection of images.

Qinghua *et al.* have used SR phenomenon for line detection from noisy images based on Radon transform [34] in 2003. They have shown that the bistable stochastic resonance based Radon transform can easily extract weak lines from very strong noisy images. This SR based Radon transform algorithm is used in the bearing-time record and the LOFAR display.

In the same year 2003 Hongler *et al.* [35] reported that the ubiquitous presence of random vibrations in vision systems can be used for edge detection. They showed mathematically and experimentally that the relevant part of the information needed to detect the edges of an image is contained in the modulation of the variance of the output random signal.

A constructive action of noise for impulsive noise removal from noisy images is reported by Histacle *et al.* in 2006 [39]. This process is based on the restoration process of Perona-Malik [48] in which a Gaussian noise is purposely added. The new process of Histacle *et al.* outperform the original process of Perona Malik [48].

A novel watermarking scheme based on stochastic resonance was reported in 2006 by Guangchun *et al.* [42]. The watermark is viewed as a weak binary signal, and the median frequency discrete cosine transform (DCT) components of all the 8×8 image blocks are randomly permuted to be an approximate white Gaussian noise (WGN). When the watermark signal which are corrupted by the noise passed through the well tuned nonlinear system, output signal-to-noise ratio gets improves.

An aperiodic stochastic resonance signal processor for communication systems based on bistable dynamic mechanism is proposed for detecting baseband binary pulse amplitude modulation signals in 2008 by Sun *et al.* [43]. To demonstrate processors usability, a digital image watermarking algorithm in the DCT domain is reported. The watermark and the DCT coefficients of the image are viewed as the input signal and the noise in the watermark detection process respectively.

1.6 SR Applications in Signal Processing

Stochastic resonance phenomenon find many applications in signal processing. Some of them are discussed below.

A novel nonlinear filtering approach for detecting weak signal in heavy noise from shot data record is introduced by Asdi *et al.* [65] in 1995. Asdi *et al.* discussed an approach that relies on a nonlinear filtering of an input signal using a bistable system. They have shown that by adaptively selecting the parameters of the bistable system, it is possible to increase the ratio of the square of amplitude of a sinusoid to that of the noise intensity around the frequency of the sinusoid (stochastic resonance).

The dynamic stochastic resonance phenomenon is used in detecting periodic signals such as sinusoids [20, 53] and also detecting aperiodic signals such as pulse amplitude modulation signals [66].

Aperiodic stochastic resonance for fixed length binary sequence was studied in [67]. In communication systems, channel is always affected by the noise but it can't be removed neither by the transmitter nor by the receiver. So, it is more useful to tune the overall system (channel property with the noise) parameters with noise rather to remove the noise for the optimum response [31, 68, 69, 70].

Noise has been utilized for life support system by Suki *et al.* in 1998 [71]. Previously, doctors used mechanical ventilators to provide life support for patients at the time of respiratory failure. If this is used for a long period, these mechanical machines can cause damage to lungs, leading to partial pressure of oxygen in the arteries. In conventional mechanical ventilation, the respiratory rate and volume of air inspired per breath are fixed, although during natural breathing these parameters vary appreciably. Therefore, a computer-controlled ventilator has been introduced by Suki *et al.* in 1998 [71], that can use noise to mimic this variability. They investigated a conceptual model of lung injury in which the partial pressure of arterial oxygen is improved significantly by computer controlled rather than conventional mechanical ventilation.

A real time human balance control system is developed by Collins *et al.* [72] in 2003. Here low-level input noise (mechanical or electrical) is used to take out the pain in movement of body part in humans. Therefore, it improve the performance of the human balance control. This mechanism is very helpful for patients who are not able to stand due to paralysis attack.

Application of SSR in information theory and neural coding was developed by McDonnel *et al.* respectively [73, 74]. This mechanism is very helpful for data communications.

SR-based technique has been used to create a novel class of medical devices (such as vibrating insoles) for enhancing sensory and motor function in elderly, patients with diabetic neuropathy, and patients with stroke [75].

1.7 The Layout of the Thesis

A brief overview of the work carried out in the thesis and organization of the same are summarized below.

Chapter 1 presents the motivation and objective of the thesis works. A brief introduction to stochastic resonance (SR) and its variants: Non-linear non-dynamic SR, non-linear dynamic SR and suprathreshold SR (SSR) have been presented in this chapter. A review of reported literature on SR applications in image and signal processing is also presented.

Chapter 2 proposes a generalized expression of signal-to-noise ratio (SNR) and power spectral density (PSD) for combinations of n sinusoidal input signals having different amplitudes, frequency and phase. These expressions are plotted with respect to noise standard deviation. Applicability of stochastic resonance for enhancement of very low contrast images is introduced in this chapter. The threshold expression for stochastic resonance phenomenon is also derived. Later on, to overcome the time complexity of enhancement algorithm, optimal noise standard deviation is derived which is based on the probability of goodness of an image.

Chapter 3 presents a SSR technique for segmentation of noisy, blurred color images with different intensity values. In this approach, Gaussian noise and uniform noise is added separately for segmentation of input images. Three parameters namely correlation coefficient, change in object position and number of mismatch pixels are used as performance measure. Performance of the proposed segmentation technique is compared with that of SR-extended segmentation algorithm [41], watershed segmentation algorithm [44], marker controlled watershed segmentation [44] and integrated region mapping based segmentation [91] and found to be significantly better.

Chapter 4 focuses on watermark detection based on suprathreshold stochastic resonance (SSR). Uniform noise of mean zero and variance one with a specific seed value is considered as watermark. Two new techniques are reported for detection of watermark based on SSR. The first technique is called SSR and single threshold, in which different thresholded frames are averaged to get single frame. This single frame is used in the detection process. The second technique is called SSR and maximizing network, in which different thresholded frames are maximized to get single frame. This single frame is used in the detection process. Mathematically and experimentally it has been observed that the correlation improves significantly in both these approaches. Latter on, the whole experiment is repeated using Gaussian noise with specific seed values as a watermark and the same is used for watermark detection process using SSR. Experimentally it is observed that the response is better for these cases also.

Chapter 5 presents the detection of logo from distorted watermarked images using stochastic resonance. A non-linear dynamic SR phenomenon is used for logo detection. In our proposed work, combined DWT and DCT with the stochastic resonance is used for logo detection. The proposed technique is compared to the existing techniques and found to perform better in terms of correlation coefficient and peak signal-to-noise-ratio between extracted logo and embedded logo.

Generally in logo detection, the extracted logo quality degrades in the presence of strong attacks. Stochastic resonance improves the logo detection even in the presence of strong attacks. We observed experimentally that the correlation coefficients when the watermarked image suffers pulse noise attack or the Gaussian noise attack is more than that when the watermarked image does not suffer from any attack. So, the noise imposed by the attack is helpful to the logo detection.

The final chapter summarizes the important conclusions drawn from the work carried out in the thesis. The comparative results are also discussed in brief. The advantage and disadvantages of all the proposed methods are also highlighted. The thesis concludes by suggesting scope for future work.

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