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Bat optimization based neuron model of stochastic resonance for the enhancement of MR images

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ABSTRACT

Stochastic resonance (SR) performs the enhancement of the low in contrast image with the help of noise. The present paper proposes a modified neuron model based stochastic resonance approach applied for the enhancement of T1 weighted, T2 weighted, fluid-attenuated inversion recovery (FLAIR) and diffusion-weighted imaging (DWI) sequences of magnetic resonance imaging. Multi objective bat algorithm has been applied to tune the parameters of the modified neuron model for the maximization of two competitive image performance indices contrast enhancement factor (F) and mean opinion score (MOS). The quality of processed image depends on the choice of these image performance indices rather the selection of SR parameters. The proposed approach performs well on enhancement of magnetic resonance (MR) images, as a result there is improvement in the gray-white matter differentiation and has been found helpful in the better diagnosis of MR images.

1. Introduction

Magnetic resonance imaging (MRI) is a well-established tool for the structural investigations of brain neuropathology. MRI sequences such as T1, T2, DWI and FLAIR find application in analysis and diagnosis of various neuro-pathologies and anatomical structure study of brain. T1 weighted sequence closely approximates the macroscopically appearances of the tissues and helps to obtain morphological information. T2 weighted sequence generally identifies the edema in soft tissues. DWI is an isotropic T2 weighted maps, usually detect acute pathology such as ischemic stroke and cellular tumor whereas FLAIR sequence removes the effect of fluid and identifies the subtle changes at the periphery of the hemispheres and in the periventricular region near to cerebrospinal fluid. More or less all sequences of MRI suffer from low contrast and low signal to noise ratio (SNR), which lead to poor readability and hence may affect the diagnosis. Hence, these images require de-noising and contrast enhancement for better quality and readability.

Noise in the MR images can be modeled as the Rician distributed [1]. Blind suppression of noise using Gaussian filter and median filter are prone to remove the detailed features of the original image [2]. Therefore, noise estimation is required to filter the noisy images. Rician noise in case of MR images has been estimated and reduced using following approaches: variance-stabilization approach [3], non-local PCA [4], iterative

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bilateral filter [5] and LMMSE approach [6]. All of these approaches perform the MRI de-noising however, they does not enhance the contrast of MR images. Images produced by low to mid field MRI and DWI sequences usually suffer from low dynamic range of intensities and further these may also corrupt by the presence of Rician distributed noise. There were many techniques proposed in spatial domain for the enhancement of MR images [7–9], all of these approaches were able address the issue of contrast enhancement however they did not performed well at the front of noise suppression. Therefore, MR images require contrast enhancement with lesser noise for better readability and analysis of the pathology.

Stochastic resonance (SR) based enhancement has emerged as a good approach to reduce noise as well to enhance contrast of the image in a single step. SR is a phenomenon where non-linear system utilizes the noise itself for the enhancement of the image to improve SNR, contrast and details. Previously, non-dynamic SR based enhancement approach has been applied to photographic and synthetic images [10], where the noise of different standard deviations was added to the image and enhancement process was carried out using predetermined threshold values, the enhanced images so obtained were analyzed manually to select the best image. Further, some studies used optimization algorithms to select the best image based on its performance matrices [11,12]. However, the optimization of external noise added to image with objective to improve quality could have produced better results. There are models based on SR with non-linear dynamic termed as dynamic SR (DSR), which derives the input signal in the presence of noise, further, many non-linear SR dynamics models have been proposed in the last three decades, however, the quartic bistable potential system [13], has been the most commonly used model for image enhancement. Further, implementation of DSR in digital imaging needs iterative discretization of stochastic differential equation where the parameters a,b and number of iterations (n) influences the enhancement level achieved in output image. In previous, studies enhancement of images has been done with estimated values of these parameters, and image enhancement has been carried out using non optimal parameters for MR images [14], CT images [15] and US images [16], the results of such enhancement are also non optimal. Further, DSR based study on real life photographic images used a and b to increase SNR, however, these algorithms selected the value of n manually with respect to image performance measures [17]. This approach is time consuming and tedious to obtain the appropriate value of iterations.

The proposed algorithm is a hybridization of multi-objective Bat optimization and DSR, which implements the modified neuron model of SR for optimum enhancement of brain MR images. The processed image using this model depends on model parameter (η) and number of iterations (n) [18]. It is easy and relatively faster to tune these two parameter for a desired output in comparison to quartic bistable potential model. Bat algorithm (BA) is relatively newer and efficient technique that has a balanced combination of the advantages of existing successful optimization algorithms [19]. This paper implements multi-objective bat algorithm (MOBA) to tunes the two parameters of modified neuron model of SR for the maximization of image performance measures. Rest of the paper is organized as follows: Section 2 explains the basic mechanism and simulation of the modified form of neuron model. Section 3 deals with mathematical formulations of the proposed work. Section 4 describes the principle of BA and multi-objective optimization approach. Section 5 describes the methodology of the proposed work. Section 6 shows the qualitative and quantitative analysis for T1, T2, FLAIR, DWI sequences of MRI. Section 7 provides the collusion of the work.

2. Neuron model of stochastic resonance

Stochastic resonance phenomena was first investigated for possible explanation of periodicity of the Earth's ice age where normal climate and largely ice covered states are modeled as two metastable states separated by an energy barrier [20,21]. The random fluctuation of solar system modeled as noise, which drives this bistable system. Buhmann et al. investigated a noise added neural network, which has the interconnection of neurons, noisy sets help to avoid local minima on the memory surface and speed up the learning rate [22,23]. This neural network is capable of adaptive filtering, associative memory and enhance the performance of network. The property of neuron where the graded potential of membrane exceeds a threshold, the action potential occurs was described with the help of dynamic equations. Bulsara et al. proposed mechanism of stochastic resonance for a single neuron model that enhanced the information processing of network [18]. The potential of unmodulated neuron introduced both additive and multiplicative noises [24] as shown below:

$$U(x) = \frac{x^2}{2} - \eta(t)\ln(\cosh x) \tag{1}$$

where x is a state variable representing the firing rate and $\eta(t) = \eta_0 + n_m(t)$, where $n_m(t)$ is multiplicative noise. Switching rate in the absence of periodic input defined by Kramer's formula [25]:

$$r_0 = \frac{1}{2\pi}[|U'(0)|U'(c)]^{1/2}\exp\left(\frac{-\Delta U}{D}\right), \tag{2}$$

where $U'(0)$ denotes the curvature of the well at $x = 0$, $U'(c)$ denotes the curvature of well's bottoms at $x = \pm c$, prime denotes the differentiation with respect to x and ΔU is the height of potential barrier. The motion of particle in the presence of signal and noise is given by the following dynamic equation:

$$\frac{d}{dt}x(t) = -\frac{d}{dx}U(x) + \epsilon(\sin\omega t) + n_a(t), \tag{3}$$

$$\frac{d}{dt}x(t) = -x + \eta(t)\tanh x + \epsilon(\sin\omega t) + n_a(t), \tag{4}$$

where ε is the amplitude, ω is the frequency of external input signal and $n_a(t)$ is the additive noise. Multiplicative noise $n_m(t)$ and additive noise $n_a(t)$ both are white Gaussian but uncorrelated noises. The system will remain bistable if $\epsilon < \Delta U$, hence, in the absence of noise no switching will occur.

Multiplicative noise presents with signal amplitude causes barrier height suppression in single neuron model, which suppress the effect of SR. Therefore, it is necessary to keep ΔU sufficient high to neutralize the effect of multiplicative noise to maintain the condition of bistability. The presence of Rician noise with MR image reduces the barrier height, hence,