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Optimal sub-band adaptive thresholding based edge preserved satellite image denoising using adaptive differential evolution algorithm

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ABSTRACT

An image is often corrupted by different kinds of noise during its acquisition and transmission. Conventional denoising methods can suppress the Gaussian noise effectively, but fail to maintain the quality of denoised images and may blur edges in an image. To address these short comings, this paper aims to develop an optimized adaptive thresholding function based framework for edge preserved satellite image denoising using different nature inspired algorithms which is capable of effectively removing the Gaussian noise from images without over smoothing edge details. Image denoising using adaptive thresholding functions selects the suitable threshold values to separate noise from the actual image without affecting the actual features of the image. In this approach, most widely used nature inspired optimization algorithms are exploited for learning the parameters of adaptive thresholding function required for optimum performance. It was found that the proposed adaptive differential evolution algorithm (JADE) algorithm based denoising approach has superior features and give better performance in terms of PSNR, MSE, SSIM and FSIM as compared to other methods.

1. Introduction

Image denoising is a classical image processing problem. Digital images are often distorted by the variety of noise. The term noise in digital image processing is referred to any quantity that deflects an observed pixel from its original value. The numerous kinds of noise and artifact in imaging modalities corrupt the images and reduce the image quality. Such artifacts have considerable impact on the image appearance and affect the human interpretation as well as accuracy of the computer assisted methods in various image processing applications [1]. Moreover, image enhancement, image segmentation, image classification and quantitative measurement becomes complicated and unpredictable because of mixture of noise parameters. It is clear that the removal of noise from the image facilitates the processing. Thus, denoising of images has become the fundamental step in several practical applications such as satellite imaging [2]. As a result, in order to minimize the effect of noise and improve the image quality for higher level processing, denoising pre-treatment of image signal is carried out.

In practice, most frequent distortions are due to corruption by additive noise (Gaussian), salt and pepper noise and multiplicative noise (speckle) with different characteristics. In Gaussian noise, each pixel of image is changed by a small amount from its original value. The Gaussian (normal) distribution is a very good model to represent this type of noise. This is due to central limit theorem, which states that the sum of different noises tends to approach a Gaussian distribution. Conventional linear filters remove the Gaussian noises with detriments for edge and texture details in an image. To address the problem of edge-preserving, a variety of modified Gaussian noise removal techniques has been presented [3–7]. Multiplicative noise is generally more difficult to be removed from the images than additive noise because the intensity of noise varies with the signal intensity. In salt and pepper noise, pixels in the image are very different in color or intensity unlike their surrounding pixels. A noisy pixel does not have any relation to the color of neighboring pixels. This type of artifact is caused by sharp and sudden disturbance in the image signal. This noise affects only a small number of pixels. It contains dark and white dots [8]. Remote sensing images are an essential source of information, which are used in several environmental assessment and monitoring such as climate studies, assessment of forest resources, examining marine environments agriculture, metrology, mapping, military, etc [9–11].

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In denoising, traditional spatial filters not only smooth the data and reduce the noise, but also blur the data to some extent. The main aim of denoising is to eliminate the noise particles and to retain the actual image features as much as possible. At present, many new denoising techniques have been developed and explored, such as wavelet based approach [12–14], non-local means algorithm [15–16], Bivariate Shrinkage function [17], Sparse coding shrinkage [18], Bayesian approach [19–21], principal component analysis [22], support vector machine [23], Support vector regression [24–25], compressive sensing theory [26], Bilateral filtering [27–28], Wavelet shrinkage [29] soft thresholding and hard thresholding.

These techniques can perform image smoothing/denoising and preserve the useful features and edges to a certain extent. However, each of these methods has certain limitations in terms of image quality or computational efficiency. In general, non-local means [15–16] obtains the denoised image with fine image quality but it takes relatively high computational cost in the global search for pixels with similar intensity. On the other hand, wavelet thresholding based methods and basis pursuit denoising schemes can effectively suppress the noise because of having sparse representation in most natural images when they are expressed in wavelets or a set of basis. However, these techniques are likely to be affected by the ripple artifacts. Image denoising using bilateral filter [27–28] produces fine results with advantage of easy implementation, but it has not yet attained a desirable level of applicability in terms of image quality [26]. In 2014, Zhang et al. have proposed an adaptive bilateral filter [30] based framework for image denoising which is capable of eliminating the universal noise efficiently, i.e. impulses, Gaussian noise or mixture of the two types of noises, from the images without over smoothing edge details.

Images are often affected by another type of noise known as impulse noise, which replaces the value of certain region of pixel with random value. This type of noise generally arises because of transmission error. To deal with such kind of problems, median filters are designed which can remove the impulse noise to a certain extent, with some of its enhanced performance and better feature preserving rate [31–32]. In 2005, Chan et al. [33] proposed a two-phase scheme for removing salt-and-pepper impulse noise. In the first phase, an adaptive median filter is used to identify pixels, which are likely to be contaminated by the noise. In the second phase, the image is restored using a specialized regularization method that applies only to those selected noise candidates. In case of impulse noise, median filter is found to be most effective nonlinear filter due to its powerful denoising capability and fast processing. However, when the noise level is over 50%, some details and edges are degraded by the filter. In practice, during transmission and acquisition, mixed noise together with the Gaussian and impulse noise arise simultaneously. To remove such kind of noise from noisy image, various efforts have been made [34–36].

In recent years, wavelet thresholding algorithm is found to be one of the most favorable approaches for image denoising. Many filtering techniques have been designed to get better denoised image such as averaging filter, median filter, Wiener filter, adaptive filter, etc. In these classical methods, median filter is most frequently used in nonlinear spatial filters to suppress salt and pepper noise due to its effective denoising performance. But this filtering approach does not give satisfactory results in case of Gaussian noise because it generates a blurred and smoothed image with poor feature localization and incomplete noise suppression. These artifacts take place in denoised image because median filter replaces the noisy pixel by a median value in their vicinity without taking into account the local features such as the presence of edges. In past few years, a number of efforts have been made to remove the speckle noise using wavelet transform [37–39]. Recently, some new approach has been presented using wavelet transform which works in transformed version of the noisy image and obtain the denoised image in transformed domain [40].

In literature, a wide range of wavelet thresholding approaches have been presented. Denoising in the wavelet domain may be stated as *thresholding* of DWT detailed coefficients of the noisy image, either *hard* or *soft* [41]. Hard or soft thresholding of DWT coefficients is commonly used to achieve denoising. In hard thresholding, image is preserved if it is higher than the threshold value; otherwise it is set to zero, and in soft thresholding, image is shrunk to zero by an amount of threshold. Because of having the properties like sparsity and multiscale decomposition in wavelet transform coefficients; it has attracted a number of researchers to work in the wavelet domain. These features of the wavelet domain provide flexibility to represent main energy of signal by few large coefficients and remaining energy by many small coefficients. Since, most of the noise powers are present in many small coefficients; therefore, it is essential to modify these coefficients by a certain rule to achieve the denoised image. To improve this process of denoising, researchers have tried to develop a number of advanced thresholding function.

Nasri and Pour [42] have introduced a new adaptive thresholding function based on wavelet transform based thresholding neural network (WT-TNN) methodology. The proposed function is further used in a new subband-adaptive thresholding neural network to improve the efficiency of denoising procedure. They have reported that the suggested technique outperforms the many well known other thresholding techniques such as soft, hard, garrote and other existing thresholding functions in WT-TNN methodology. Further, they claimed that the presented scheme eliminates the noise regardless of its distribution and modeling of the distribution of image wavelet coefficients. The beauty of this approach using the new adaptive thresholding function is due to simultaneous learning of parameters of thresholding function and threshold value in each sub-band of WT. But the drawback of this technique is more computational cost. Due to the usage of a steepest descent gradient technique in WT-TNN approach, computational time is increased considerably. Basically in this approach, proper initialization of threshold and thresholding parameters is very difficult to achieve fast convergence of the learning process in order to obtain the optimum values of these parameters. Therefore, to overcome the prime limitation of WT-TNN based denoising methodology, an optimized adaptive thresholding function based framework for satellite image denoising using JADE and other optimization techniques have been presented in this paper. The effective denoised results of the proposed JADE algorithms based adaptive thresholding approach is achieved due to the formulation and implementation of optimization algorithms instead of a steepest descent gradient-based LMS technique, which corresponds to superior performance with fast convergence. But more importantly, it has been examined that the proposed optimized adaptive thresholding based denoised image yields better edge preserving performance at high noise levels. After successful performance of the new adaptive thresholding function, in 2011, Bhutada et al. presented an edge preserved image enhancement technique using adaptive fusion of images which is denoised by wavelet and curvelet transform [43]. Furthermore, in 2011, wavelet transform-based thresholding neural network (WT-TNN) methodology has been proposed by Bhutada et al. to improve the computational cost of denoising problem. In this approach, they have adaptively selected the learning step size for tuning the parameter of thresholding function [44]. Subsequently, in 2012, authors have presented the PSO-based learning of sub-band adaptive thresholding function for denoising of Gaussian noise [45]. In these papers, the existing