GREY WOLF OPTIMIZATION WITH WAVELET SCHEME FOR SAR IMAGES DENOISING

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Abstract

De-noising is the reconstruction of an original image once all useless noise that is from affected images are eliminated. The image de-noising is a major challenge to researchers since the removal of noise can introduce artefacts that can result in the blurring of all images. The techniques based on the wavelet were to identify better applicability in the removal of noise owing to the capability of space-frequency and its localization. The techniques inspired by nature have an important role to play in image processing. This will bring down image blurring, noise and improves enhancement of image, image fusion, image thresholding, and image pattern recognition. The algorithm known as Grey Wolf Optimization (GWO) falls under the category of swarm intelligence and thus initiates the process of optimization using random solutions.

Keywords : Denoising, Image denoising, Wavelet-based techniques, Grey Wolf Optimization (GWO) algorithm.

I. Introduction

From the time of its origin which happened in the 1950s the Synthetic Aperture Radar (SAR) had become a new and mature technology that has been recognized to be a successful tool for imaging and in environmental monitoring. It also includes military applications needing broad imaging which are at high resolutions, glacier monitoring, and forest cover mapping. The Synthetic Aperture Radar-based images are now becoming important in various remote sensing applications [XV]. The images were captured using special equipment known as the SAR sensors that can operate in different weather conditions. Image de-noising is taken to be a key step in pre-processing in various cases more so in the problems of
pattern classification. There have been several techniques of de-noising that are proposed in the literature. The limitations of the techniques are based on the loss of its resolution and fine details found in the de-noised image. This is owing to the smoothing effect that is equally applied to the homogeneous regions and edge regions. All techniques of de-noising primarily aim at preserving the image structures and also bringing down the noise.

In image filtering, the primary aim of the technique of de-noising was the removal of noise which was irrespective of the noisy signal and its spectral content. The primary aim of the SAR image and its de-noising was improving the coefficients of backscattering found in areas that are homogeneous along with the edges found in the images. The filter will have to preserve spatial variability which denotes textural information for all areas that have a texture like the forests. The main challenge remains in cleaning images without having to sacrifice its geometric resolution. Another method of reduction of speckle-noise was the new multi-look technique that had been applied to its SAR signal and at the time of data processing of the SAR in the direction of the azimuth found in the domain of frequency [XII]. For this, there was a signal bandwidth which is split into segments that are smaller and these signals were processed in the domain of frequency. After this, they will be incoherently summed up for getting an output that has better resolutions that are radiometric and having less noise.

The primary advantage of the wavelet analysis was that it permits the use of time intervals that are long and also has precise information with low frequency. Wavelet analysis can reveal the aspects of data which have other techniques of image analysis, points of breakdown, trends, self-similarity, and derivatives. The wavelets can also get an image compressed or de-noised without degradation of its original image. There are adaptive filters that assume a speckle to be nodes that are multiplicative. One of the most common adaptive filters here is Frost’s filter.

The techniques of nature-inspired optimization have an essential role to play [XVI] in image processing. This can bring down blurring of images and noise and further improve enhancement of image, its restoration, segmentation, detection, image generation, image fusion, pattern recognition and finally image thresholding. The optimization of more than one single function is very common in problems of optimization thus needing a considerable amount of time. This indicates a single criterion not being sufficient for the decision-makers to be able to make a decision for identifying resolutions (El-henawy and Ismail 2014). The primary advantage of the GWO was its easy design, simplicity, flexibility, scalability, and capacity to be able to strike a balance between the concepts of exploration and exploitation at the time of search which results in a favourable level of convergence.

In this work, a wavelet filter along with the grey wolf optimization was proposed for the SAR. The rest of the study has been organized in the following manner. All related work in literature is discussed in Section 2. Section 3 discusses the methods used in this work. The results of the experiment are analysed in Section 4 and Section 5 concludes the work.
II. Literature Survey

Misra et al. [XIII] had stated the Synthetic Aperture Radar (SAR) based data de-noising using wavelet approach that uses a basic variance for detailed coefficients of images that were decomposed in various levels has been tested on classes of imagery of the RISAT-1 SAR. Both results and analysis from these filtering based on three data categories were depicted here.

The data of Synthetic Aperture Radar has been gaining importance in the applications of remote sensing owing to the weather and the capabilities of day and night imaging. But, the images that were obtained on completion of a set of operations that were complex had received data and this was affected by a noise that is of a grainy kind known as the speckle, and this may render the data to be challenging for further analysis. Image de-noising is a mandatory step in the domain of SAR processing. There are several filters of de-noising for the SAR images that have come up recently. The wavelet-based SAR data and techniques of de-noising were gaining a lot of popularity since it had the capability of localization of space-frequency for analysis of data at various scales. Misra and Kartikeyan [XIII] had made a new and comprehensive review of filtering techniques that are well-known for the de-noising of the SAR data.

Nair and Bhadran [XV] had made a presentation of another new approach in image de-noising for the models of speckle noise. The method proposed was a modification of the Non-Local Means and the filter methods that had performed a weighted average on the restricted and local neighbourhoods. Furthermore, this method had performed some calculation of weight that made use of the estimation function called Geman-McClure as opposed to the exponential function owing to the fact that the Geman-McClure estimator which was better for preserving the edge details. The experiments that are at different levels of noise that were based on the values of the PSNR and the SSIM values that prove the method to have outperformed all the other existing methods thus increasing the accuracy of processing a synthetic aperture radar (SAR) based images.

Zhao et al. [XX] had made a new proposal of another novel approach to image processing for improving the de-noising in the SAR images that were based on the median filter and wavelet packet. The Median filter has been adopted for removal of noise found in the domain of wavelet packet. In the initial stages, the process is introduced for the proposed approach and this is compared with the other algorithms that is made in terms of the PSNR.

The wavelet transform has represented a natural image which is better compared to the other transformations. Thus, a wavelet coefficient may be used for improving the quality of true images from noise. Chaudhari and Mahajan [I] primarily aim at eliminating both Gaussian and the salt-pepper noise found in the domain of wavelet transform. After this, a threshold based on both soft and hard thresholds were developed. Lastly, there was a de-noised image that had been compared to the original one with certain statistical indices that are quantified. They may be like the PSNR, SNR and the MSE for various noise variances and the results of the experiment have proved the effectiveness of this method.
Mustafa et al [XIV] had made a new proposal to de-noise the medical images with various types of wavelet transform like the Haar, the Daubechies, the Symlets and the Bi-orthogonal transform. For the purpose of this paper, the quality of noise image was evaluated with the parameters of filter assessment such as the Peak Signal to Noise Ratio (PSNR), the Variance and the Mean Square Error (MSE). The observations were to form some numerical results and present a new algorithm to reduce mean square error and also achieve the best value for the peak signal to noise ratio (PSNR). The paper also has the wavelet which is based on a de-noising algorithm which was investigated based on medical images and their threshold. Wavelet analysis is a method that has a major effect on noise removal in a signal. Xizhi [XVIII] had outlined the wavelet analysis principles and based on the features of a multi-scale edge for the wavelet, the de-noising method was analysed using the orthogonal wavelet transform. This had both soft, as well as a hard threshold. There was a new de-noising method which was put forward on the basis of the wavelet transform for addressing such a dilemma in noise reduction along with protection of an image edge. So the de-noising of a signal of a two-dimensional image that was based on the MATLAB was realised.

Xue [XIX] had made a new proposal of another method that was very effective in which the SAR image and its de-noising was made by an analysis of the SAR image and its distribution characteristic in the domain of wavelets. Firstly, the logarithmically transformed image will be decomposed using the wavelet transform. Next, for overcoming the challenge of selecting a threshold in the SAR image speckle reduction that was based on the wavelet transform, there were child images that were decomposed and filtered using fuzzy median value filters. Lastly, in accordance to the filtered child images, the image was reconstructed and given an exponential transform to get the SAR image filtered. The results of the experiment proved the new method to be effective in the reduction of SAR speckle.

Ramson et al [XVII] had made a presentation of a short review of the algorithms that were nature-inspired. They are Plant optimization, Chemical reaction optimization, Water wave optimization, Lion optimization, Bumblebees mating, Elephant herding optimization, Cuckoo Search Algorithm, Firefly optimization, Particle Swarm Optimization, Artificial bee optimization, Ant colony optimization, Grey wolf optimization, Genetic programming, and the Genetic Algorithm. There was a raven roosting algorithm which was within the insight of applying algorithms of optimization in the image processing fields that are advanced.

Faris et al [IV] had proposed a GWO which has been gaining plenty of interest among audiences in various domains within a short time span. So, for this review paper, there have been plenty of research publications that make use of the GWO that have been overviewed and further summarized. In the initial stages, there had been some introductory information on the GWO that was provided to illustrate the context of natural foundation and the optimization conceptual framework which was related. The primary operations of the GWO had been discussed procedurally and theoretical foundation described. Also, the GWO and its recent versions have been discussed in detail and have been grouped into the modified, the hybridized and the paralleled versions. The applications are part of the domains of power engineering, image processing, machine learning, networking, environmental applications, and
bioinformatics. There is an open-source of the GWO software that has been provided. This review paper has been concluded by means of providing a summary of the conclusion of the foundation of the GWI and also suggested different future directions that were investigated further.

III. Methodology

The section provides details on frost filter, the wavelet filter, and the grey wolf optimization.

a. Frost Filter

A Frost filter is a Wiener filter that is adaptive that convolves pixel values in a fixed window size having an exponential impulse response which is given as per equation (1):

\[
m = \exp[-KC_y(t_0)|t|]
\]

\[
C_y = \sigma_y / \bar{y}
\]

(1)

Where the k denotes filter parameters, \( t_0 \) which represent the actual location of the pixel that is processed and \(|t|\) denotes the actual distance which is measured from the pixel \( t_0 \). This is a response which results from the autogressive exponential model which has been assumed for the reflectivity of scene x.

b. Wavelet Filter

The wavelets are being used for the last decade for different tasks of image processing. The analysis of the time-frequency domain has made the technique extremely useful in the signal domains or image compression, enhancement of image, de-noising, fractals, and enhancement of resolutions. The basic idea behind this was analysing signals in accordance with scale. There are several advantages to the Wavelet transforms over the traditional Fourier transforms in representing various functions with discontinuities or sharp peaks to accurately deconstruct and reconstruct the finite, the non-periodic and the non-stationary signals. The wavelet-based images and their analysis, de-noising, and enhancement for procuring better performance owing to properties of sparsity and its multi-resolution structures.

The Wavelet transforms have the trait of a multiresolution analysis along with the ability to transform the local features of the signals in the time and the frequency domain. For the wavelet which is \( \psi \) there may be compact support along with vanishing moments \( n \) as in equation (2):

\[
\int_{-\infty}^{+\infty} t^k \psi(t)dt = 0, \ for \ 0 \leq k \leq n
\]

(2)
There has been a function $\psi$ with fast decay as shown in (3)

$$\psi(t) = (-1)^n \frac{d^n \theta(t)}{dt^n}$$

(3)

Once this is done, wavelet transform for signal $f$ is shown as in (4):

$$Wf(u, s) = s^n \frac{d^n}{du^n} (f \ast \overline{\theta}_s)(u)$$

(4)

Wherein, $\overline{\theta}_s(t) = s^{-1/2} \theta(-t/s)$ denotes either the time or space coordinate and $s$ denotes its scale. The consequence will be the wavelet transform which is $Wf(u, s)$ and this is the $n$th-order derivative for the averaging of $f$ that has $\overline{\theta}_s$ on the domain proportional to $s$.

Viewing from the wavelet transform energy point, wavelet transform for the Gauss noise may continue to exhibit the Gauss distribution and this is equally distributed in various parts of the phasic space. But, for the band limit signal, the coefficients of the wavelet transform on some of the parts will contribute to the speckle and this means the distributed energy $t$ sent to all the parts of the wavelet coefficients, and only some of them have contributed to the signal. The wavelet coefficients are thus grouped into two different parts, the first type of wavelet coefficient will come from the speckle and its wavelet transform and breadth of such types will be less but their numbers are more. The next type of wavelet coefficient is from the signal and its wavelet transform and for this, the breadth is more but the numbers are less. Thus, a new method to bring down speckle has been proposed based on the coefficients of wavelet transform and the distribution of speckle and signal [XIX]. For the signal of the wavelet coefficients, there is a threshold (that has been decided by the self-adaptive method or the experience) that has been chosen. The wavelet coefficients which are higher compared to the threshold will be considered as the second type of coefficients. These wavelet coefficients that are less compared to the threshold will be regarded as the first type of wavelet coefficient and thus be reduced.

b. Proposed Grey Wolf Optimization (GWO)

Optimization denotes the process that searches for the vector within a function which can generate a solution that is optimal. There is an extreme value for the optimal solutions and all its feasible values indicate a variable solution. The problems of optimization may be resolved by means of applying the algorithms of optimization. The nature of these algorithms has been factored for a classification that is divided into two which are the stochastic and the deterministic algorithms. The first one generates various other solutions that have an initial value which is the same and this will not employ any gradients. Further, in spite of the fact that the final values are different, they tend to merge within the same optimal solution in the accuracy that is given. There have been two different types of stochastic algorithms identified which are the Heuristic and the Meta-heuristic. There may be another set of problems of nonlinear numerical global optimization that may be effectively solved with these algorithms. The metaheuristic algorithms attempt at striking a balance between the randomization
of global search and the local search. The Grey Wolf Optimization is an algorithm which is inspired biologically in different fusion applications found in the literature [II]. GWO algorithm has been inspired by the nature of the grey wolves for identifying an optimal method of hunting for their prey. The GWO is applied with a similar mechanism in nature in which it follows a pack hierarchy to organize various roles in the pack of wolves. In the GWO, the members of the pack are grouped into four on the basis of the type of role of the wolf to help in the advancement of the process of hunting. These are the alpha, the beta, the delta, and the omega. Alpha refers to the solution which is found in hunting until that point. Dividing the population into four is for complying with the hierarchy of domination of the grey wolves. The inventors had conducted extensive experiments to observe four different group results and their average to benchmark problems and the average performance for case studies of the real-world. But when considering either more or less of the groups that are investigated in the future to solve problems of a large scale this may be applicable. A flowchart for the Grey Wolf Optimization has been shown in Figure 1.

![Flowchart of Proposed Grey Wolf Optimization](image)

**Figure 1: Flowchart of Proposed Grey Wolf Optimization**

The GWO [IV] is a search process like the other algorithms that are based on the SI beginning with the creation of a random grey wolf population. Once this is done,
there are four other groups of wolves for which positions are formed and targets are measured. Every wolf in this will represent the candidate solution and this will be updated by means of the process of search. Also, the GWO will apply some powerful operations that are controlled using two different parameters for maintaining both exploration and exploitation. In spite of the similarity found in the manner in which the GWO has a global optimum which is compared to that of the other algorithms that are based on population, there is a mathematical model for this which is novel. It permits the reallocation of a solution which is around a new n-dimensional search space that simulates chasing and also the encircling of preys by the grey wolves.

GWO algorithm will mimic the nature of hunting of the family of grey wolves that normally are in a pack. They have a dominant 4 level of the hierarchy and the size of the pack varies between 5 and 12. In the social hierarchy of the grey wolf, the best candidate is known as the alpha (α), and these are dominant in the pack. The next is the beta (β), and these are subordinates to alpha wolves. In case the alpha wolves are found to be absent in their pack, the beta will lead. The wolves that are the lowest in the rank are known as the omega (ω). These omega wolves will have to submit to the other wolves and are permitted to eat as the last in the pack. The wolves which are not the alpha, beta or the omega are known as the delta (δ). These delta wolves will have to obey the alpha and the beta wolves but can dominate the omega wolves [III].

IV. Results and Discussion

For experiments, the Frost filter, wavelet filter optimization using GWO are used. Datasets such as capitol, china lake, Pentagon, DC and abq_apt are considered. Table 1 shows the parameter of grey wolf optimization. The Mean Squared Error (MSE), Peak Signal to Noise Ratio (PSNR) and standard deviation/mean as shown in tables 1 to 3 and figures 2 to 4.

| Parameters                | Values |
|---------------------------|--------|
| Number of Wolves          | 5      |
| Number of Iterations      | 100    |
| Number of grids per dimension | 10    |

Table 1: Parameters of Grey Wolf Optimization

MSE: It shows average square difference of the pixels all through the image between the original image (speckled) \( I_s \) and De-speckled image \( I_d \). A low MSE implies that there is a considerable filter performance (Wu) [555]. However, smaller MSE values are not always related to adequate visual quality as in equation (5):

\[
MSE = \frac{\sum I_s(r,c) - I_d(r,c))^2}{R \times C}
\]  

(5)

Wherein \( R \times C \) represents the size of image.
PSNR: It is most often utilized as a metric of reconstruction quality in image compression as well as image denoising and so on. The PSNR is expressed as in equation (6):

$$PSNR = 10 \log_{10} \left( \frac{255^2}{MSE} \right)$$  \hspace{1cm} (6)

Higher the PSNR, better the speckle reduction of images.

| Image     | Frost | Wavelet Filter | Grey Wolf Optimization |
|-----------|-------|----------------|------------------------|
| Capitol   | 64.25 | 49.4          | 20.32                  |
| China Lake| 63.67 | 49.69         | 23.44                  |
| Pentagon  | 50.24 | 40.52         | 16.4                   |
| DC        | 51.62 | 42.83         | 20.26                  |
| abq_apt   | 49.22 | 36.12         | 17.19                  |

Table 2: MSE for Proposed Grey Wolf Optimization

From the table 2 and figure 2, it can be observed that the MSE of proposed Grey wolf optimization is decreased by 103.9% &83.42% than capitol, by 92.37% &71.8% than China lake, by 101.6% &84.8% than pentagon, by 87.26% &71.55% than DC and by 96.5% &71.02% than abq_apt compared for Frost Filter and wavelet filter.
Table 3: PSNR for Proposed Grey Wolf Optimization

| Image     | Frost | Wavelet Filter | Grey Wolf Optimization |
|-----------|-------|----------------|------------------------|
| Capitol   | 30.05 | 31.19          | 33.61                  |
| China Lake| 30.09 | 31.17          | 32.88                  |
| Pentagon  | 31.12 | 32.05          | 34.15                  |
| DC        | 31    | 31.81          | 33.62                  |
| abq_apt   | 31.21 | 32.55          | 34.32                  |

Table 4: Standard Deviation/Mean for Proposed Grey Wolf Optimization

| Std. Dev / Mean | Frost | Wavelet Filter | Grey Wolf Optimization |
|-----------------|-------|----------------|------------------------|
| Capitol         | 0.46  | 0.42           | 0.33                   |
| China Lake      | 0.49  | 0.46           | 0.35                   |
| Pentagon        | 0.43  | 0.4            | 0.29                   |
| DC              | 0.51  | 0.49           | 0.36                   |
| abq_apt         | 0.47  | 0.44           | 0.35                   |

Figure 2: PSNR for Proposed Grey Wolf Optimization

From the table 3 and figure 3, it can be observed that the PSNR of proposed Grey wolf optimization is decreased by 11.2% & 7.5% than capitol, by 8.9% & 5.34% than China lake, by 9.3% & 6.34% than pentagon, by 8.1% & 5.53% than DC and by 9.5% & 5.29% than abq_apt compared for Frost Filter and wavelet filter.
From the table 4 and figure 4, it can be observed that the standard deviation/mean of proposed Grey wolf optimization is decreased by 32.9% &24% than capitol, by 33.33% &27.2% than China lake, by 38.89% &31.9% than pentagon, by 34.48% &30.59% than DC and by 29.27% &22.8% than abq_apt compared for Frost Filter and wavelet filter.

V. Conclusion

De-noising or the estimation of various functions will include the reconstitution of signals and observations to be a useful signal that is corrupt by noise. These methods are based on the wavelet representations yielding simple algorithms which were very powerful and also very easy to work on. Image de-noising estimation is a major challenge to researchers owing to removal of noise that introduces the artefacts resulting in a challenge to researchers. The results have proved the MSE of the Grey wolf optimization which has been reduced by about 103.9% and 83.42% compared to the capitol, by about 92.37% and 71.8% than the China lake, by about 101.6% and 84.8% than the pentagon, by about 87.26% and 71.55% than the DC and by about 96.5% and 71.02% than the abq_apt compared for the Frost Filter and the wavelet filter. PSNR for the Grey wolf optimization is lower by about 11.2% and 7.5% than the capitol, by about 8.9% and 5.34% than the China lake, by about 9.3% and 6.34% than the pentagon, by about 8.1% and 5.53% than the DC and finally by about 9.5% and 5.29% than the abq_apt when compared to the Frost Filter and the wavelet filter.
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