FUZZY MECHANISM FOR GAUSSIAN NOISE REDUCTION FOR SATELLITE IMAGE ENHANCEMENT

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ABSTRACT

Noise removal or noise reduction is one of the thrust research dimensions in the field of image processing, computer vision and pattern recognition. This paper envisages fuzzy mechanism towards gaussian noise reduction for satellite image processing. The membership functions generated using image histogram is considered. Then noise removal is carried out by fuzzy technique followed up with pixel classification, restoration and filtering. Images are taken from multispectral datasets from Quickbird, Geoeye, SPOT and IKONOS satellite. Performance metrics such as ERGAS, QAVE, RASE, SAM, FCC, PSNR, MSSIM and RMSE are taken and the results shows that the proposed mechanism outperforms than that of the existing methods.

Keywords: *Satellite Image, Noise Removal, Pixel Classification, Restoration, Filtering, Image Dataset.*

1. INTRODUCTION

Satellite image processing is fetching a significant importance recent years due to its wide range of applications in military security, agriculture, fisheries, surveillance and monitoring, etc. Satellite image processing is performed by making use of computer algorithms on satellite images to perform certain processing / tasks which have been used for the image fusion, feature extraction, segmentation, rendering, and even pattern recognition and many other satellite image operations.

Image enhancement is the technique of adjusting digital images so that the adjusted images are more efficient for further analysis. It can be removing noise, sharpening, or even brightening the image. It makes the image easier to understand and process the important features. Denoising, smoothing, and simplification are main problems in digital image processing. They mainly target on enhancing the quality of an image as a preprocessing step. It is possible to for these approaches to identify the parts of the image to be enhanced, and which are the noise to be removed as images are corrupted and meaningful necessary information are lost particularly by noise. Denoising also called as noise reduction or noise removal is one such preprocessing task which reduces or removes noise from the satellite images. Once after removal / reducing of noise from the satellite images the resultant image will have wide range implications in further processing. This research work mainly focuses on noise reduction by applying techniques such as fuzzy based noise removal, pixel classification, restoration and filtering.

2. RELATED WORKS

Yun Ling et al [1] have presented an adaptive tone-preserved algorithm for image detail enhancement in order to retain the tonal distribution of the input image and avoid experiential manipulation. At first, domain transform based multi-scale image decomposition is carried out to quickly divide the input image into a base image which contains the coarse-scale image information, and the detail layers which contain the fine-scale details. Then, during the process of detail enhancement and synthesis, the authors constructed an adaptive detail enhancement function based on the edge response, to prevent the exaggeration of strong edges and increase the enhancing magnitude of small details. Finally, in order to keep the color values of the input image and the gradient values of the detail enhanced image, a tonal correction algorithm based on energy optimization is presented to eliminate the distinct tonal differences of the enhanced image from the input image. Their experimental results showed that tone-consistent image detail enhancement effect is available for arbitrary input images with unified parameters setting, which is superior to the state-of-the-art methods.

In the study conducted by Kumar et al [5], an improved multi-band satellite contrast enhancement technique based on the singular value decomposition (SVD) and discrete cosine transform (DCT) was proposed for the feature extraction of low-contrast satellite images using normalized difference vegetation index (NDVI) technique. Their method employs multi-spectral remote sensing data technique to find the spectral signature of different objects such as the vegetation index and land cover classification presented in the satellite image. Their proposed technique converts the image into the SVD-DCT domain and after normalising the singular value matrix; the enhanced image is reconstructed by using inverse DCT. The visual and quantitative results included in this study clearly show the increased efficiency and flexibility of the proposed method over the existing methods. Their simulation results showed that the enhancement-based NDVI using DCT-SVD technique is highly useful to detect the surface features of the visible area which are extremely beneficial for municipal planning and management.

In [7] Bhandari et al have presented wavelet filter based low contrast multispectral remote sensing image enhancement by using singular value decomposition (SVD). The input image is decomposed into the four frequency subbands through discrete wavelet transform (DWT), and estimates the singular value matrix of the low-low subband image and then, it reconstructs the enhanced image by applying inverse DWT. Their technique is especially useful for enhancement of INSAT as well as LANDSAT satellite images for better feature extraction. The singular value matrix represents the intensity information of the given image, and any change on the singular values changes the intensity of the input image. Their proposed technique converts the image into DWT-SVD domain and after normalizing the singular value matrix; the enhanced image is reconstructed with the help of IDWT. The visual and quantitative results clearly show the edge sharpness, increased efficiency and flexibility of the proposed method based on Meyer wavelet and SVD over the various wavelet filters and also with exiting GHE technique. Their experimental results (Mean, Standard Deviation, MSE and PSNR) derived from Meyer wavelet and SVD show the superiority of the proposed method over conventional methods.

In the process of satellite imaging, the observed image is blurred by optical system and atmospheric effects and corrupted by additive noise. The image restoration method known as Wiener deconvolution intervenes to estimate from the degraded image an image as close as possible to the original image. The effectiveness of this method obviously depends on the regularization term which requires a priori knowledge of the power spectral density of the original image that is rarely, if ever, accessible, hence the estimation of approximate values can affect the restored image quality. In [14] Aouinti et al came up with the idea consisted of applying the genetic approach to the Wiener deconvolution for satellite image restoration through the optimization of this regularization term in order to achieve the best possible result.

Sajid and Khurshid [15] proposed Recursive Least Square (RLS) adaptive algorithm which is used for image restoration from highly noise corrupted images. The implementation of their proposed methodology is being carried out by estimating the noise patterns of wireless channel through configuring System Identification with RLS adaptive algorithm. Then, these estimated noise patterns are eliminated by configuring Signal Enhancement with RLS algorithm. The restored images are functioned for further denoising and enhancement techniques. Performance is evaluated by means of Human Visual System, quantitative measures in terms of MSE, RMSE, SNR & PSNR and by graphical measures. Their experimental results demonstrated that RLS adaptive algorithm efficiently eliminated noise from distorted images and delivered a virtuous evaluation without abundant degradation in performance.

Zhang and Man [16] have proposed a satellite image adaptive restoration method which avoids ringing artifacts at the image boundary and retains oriented features. Their method combines periodic plus smooth image decomposition with complex wavelet packet transforms. The framework first decomposes a degraded satellite image into the sum of a “periodic component” and a “smooth component”. The Bayesian method is then used to estimate the modulation transfer function degradation parameters and the noise. The periodic component is deconvoluted using complex wavelet packet transforms with the deconvolution result of the periodic component then combined with the smooth component to get the final recovered result. Their test results showed that their strategy effectively avoids ringing artifacts while preserving local image details.

Thriveni and Ramashri [17] proposed a DWT-PCA based fusion and Morphological gradient for enhancement of Satellite images. The input image is decomposed into different sub bands through DWT. PCA based fusion is apply on the low-low sub band, and input image for contrast enhancement. IDWT is used to reconstructs the enhanced image. To achieve sharper boundary discontinuities of image, an intermediate stage estimating the fine detail sub bands is required. This has been done by the success of threshold decomposition, morphological gradient based operators are used to detect the locations of the edges and sharpen the detected edges. Their proposed method has been shown that improved visibility and perceptibility of various digital satellite images.

Aedla [18] et al has presented a new contrast enhancement technique for satellite images based on clipping or plateau histogram equalization. Their technique adopted Bi-Histogram Equalization with Plateau Limit (BHEPL) for image decomposition and Self-Adaptive Plateau Histogram Equalization (SAPHE) for threshold calculation. Their proposed method has been compared with existing methods such as Histogram Equalization (HE), Brightness Preserving Bi-Histogram Equalization (BBHE), Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE), Dynamic Histogram Equalization (DHE), Bi-Histogram Equalization with Plateau Limit (BHEPL) and Self-Adaptive Plateau Histogram Equalization (SAPHE) with image quality measures such as Absolute Mean Brightness Error (AMBE) and Peak-Signal to Noise Ratio (PSNR).

Soni et al [19] proposed an improved method based on evolutionary algorithms for denoising of satellite images. In their approach, the stochastic global optimisation techniques such as Cuckoo Search (CS) algorithm, artificial bee colony (ABC), and particle swarm optimisation (PSO) technique and their different variants are exploited for learning the parameters of adaptive thresholding function required for optimum performance. It was found that the CS algorithm and ABC algorithm-based denoising approach gave better performance in terms of edge preservation index or edge keeping index (EPI or EKI) peak signal-to-noise ratio (PSNR) and signal-to-noise ratio (SNR) as compared to PSO-based denoising approach. Their proposed technique has been tested on satellite images. The quantitative (EPI, PSNR and SNR) and visual (denoised images) results show superiority of the proposed technique over conventional and state-of-the-art image denoising techniques.

Bidwai and Tuptewar [20] have developed a method to enhance the quality of image. The enhancement is done both with respect to resolution as well as contrast. Their proposed technique uses DWT and SVD. Their technique decomposes the input image into four sub-bands by using DWT and estimates singular value matrix of low frequency sub-band image, then it reconstructs enhanced image by applying inverse DWT. Their technique is applied to grey level, colour image and satellite image and their comparative analysis were done. Their experimental results showed the superiority of their proposed method over conventional techniques.

Thus to Summarize the above study:

- Adaptive tone-preserved algorithm showed tone-consistent image detail enhancement effect is available for arbitrary input images with unified parameters setting.

- SVD and DCT show the increased efficiency and flexibility and detect the surface features of the visible area which are extremely beneficial for municipal planning and management.

- SVD provides better feature extraction, edge sharpness, increased efficiency and flexibility.

- Wiener deconvolution method requires a priori knowledge of the power spectral density of the original image and if accessible, the estimation of approximate values can affect the restored image quality.

- Recursive Least Square (RLS) adaptive algorithm used for highly noise corrupted images efficiently eliminated noise from distorted images and without abundant degradation in performance.

- Satellite image adaptive restoration method avoids ringing artifacts at the image

- DWT-PCA based fusion and Morphological gradient for enhancement of Satellite images shows that improved visibility and perceptibility of images.

- Global optimization techniques such as Cuckoo Search algorithm, artificial bee colony, and particle swarm optimization technique improved quantitative and visual results

3. PROPOSED WORK

Histogram smoothing is the conventional technique used for performing Image pre-processing. It is used in order to remove spurious and noisy components. Smoothed histograms are commonly obtained with the help of kernel convolution and this research work aims in proposing distance based fuzzy mechanism for Gaussian noise removal. The concept of fuzzy logic was first introduced by Lotfi Zadeh.

In standard fuzzy set theory, a fuzzy set F (over the space X) is defined by a membership function such μ(x) ∈[0, 1][20]. In our proposed work fuzzy set A, the membership grade M_A is expressed as an interval rather than as a precise point (Ais defined over a crisp universe of discourse X as

$$M_A(x) = [\mu_L(x),\mu_U(x)] \quad (1)$$

$$\delta(x)(\delta(x) = \mu_U(x) - \mu_L(x)) \quad (2)$$

is the range of uncertainty in specifying the membership grades. It is notable that this will help in performing noise reduction in image processing. The total amount of uncertainty is difficult to be calculated in the case of FSs, and particularly when images are corrupted with noise. It is presumed that the image I is defined on an M×N square lattice, and each pixel as (m, n). For an image subset I⊆X, the histogram h(g) is defined as the (linear) index of fuzziness γ as,

$$\gamma(I) = \frac{1}{MN}\sum_{g=0}^{G-1}[h(g).(\mu_U(g)-\mu_L(g)] \quad (3)$$

An adaptive fuzziness index on a fuzzy partition of h(g), can be derived as

$$\Gamma(x) = \frac{1}{MN}\sum_{g=0}^{G-1}[h(g).(\mu_U(g)-\mu_L(g)]$$
$$\frac{1}{MN}\sum_{g=0}^{G-1}[\Delta_g(x)] \quad (4)$$

where X={0, ..., G −1}and x, g∈X, and $\mu_U(x)$, $\mu_L(x)$ are defined. The noise detection process is based on the peak detection of Γ that gives a global description of the uniform regions of an image across intensity levels. Each peak Γ_{max} of Γ is associated with a uniform region, and the local maxima of Γ_{max} (the peaks of Γ(x)) make it possible to locate the regions of an image. After the significant maxima of $\Gamma_{(x)}$are selected (peak detection), the local minima are obtained by finding the minimum values around a local maximum. The local minima are used to construct pixel classes, each pixel class is built from the grey-level values g (m, n) found between two local minima and is presented in the Algorithm 1.

Algorithm – 1: Pixel classification and image restoration

Input: Compute $\Gamma(x) = \frac{1}{MN}\sum_{g=0}^{G-1}[\Delta_g(x)]$

Find significant peaks to obtain the value L and the L values O_{max} (image regions R_l)
for each significant peak $l \in \{0,\cdots,L\}$ do
  Find $t_{min}(l), t_{max}(l)$, the grey-level values corresponding to the boundaries of R_l for which O is minimum $R_l = [t_{min}(l), t_{max}(l)]$
end for
for each pixel $g(n, m)$ of noisy image I do
  if grey level x of $g(n, m) \in R_l$ with $l \in \{0,\cdots,L\}$ then
    $V(n, m) = g(n, m)$
  else
    $V(n, m) = med(n, m)$
  end if
end for

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Thus the pixel classes produce image filtering (that is to say homogeneous regions in an image). Pixels are classified into two groups: noise-free pixels (if they belong to pixel classes), and noisy pixels in the other case. Let *med* (m, n) be the median value of pixels in a local window of size 3 ×3in the surrounding of g (m, n). Median filter *med* (m, n)is applied to all pixels g (m, n) identified as corrupted while keeping the rest of the pixels identified as noise-free. Thus the image restoration is summed up Algorithm - 1. The image filtering with two heuristic parameters α and σ is made according to Algorithm – 2.

Algorithm – 2: Image Filtering

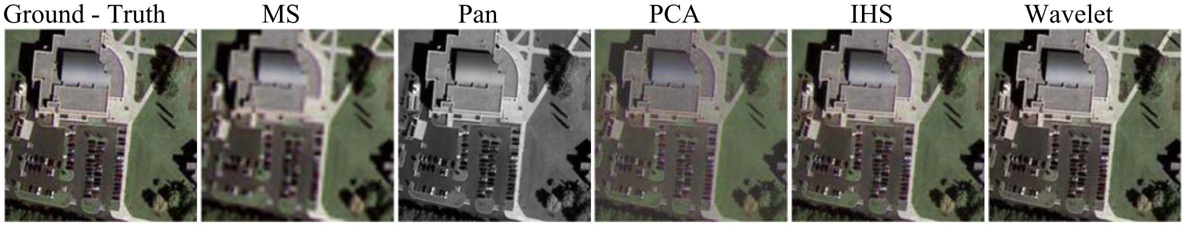
Input: an $M \times N$ grey-level image I
begin
Step 1: Compute IVFS entropy $O(x)$ using Eq.(4), with two heuristic parameters α and σ
Step 2: Find significant peaks corresponding to O_{max}
Step 3: For each significant peak classify pixels
Step 4: Restoration phase: compute $V(n, m)$
End
Output: the noise removed enhanced image V

4 EXPERIMENT SCENARIO WITH RESULTS AND DISCUSSIONS

The performance of the proposed work is evaluated on multispectral datasets from Quickbird, Geoeye, SPOT and IKONOS satellites. The resolution of Pan Images ranges from 0.41 m to 1.5 m. It is noteworthy that almost all the matching Ms Images contains lower pixel rate and has blue, green, red and near-infrared bands. The RGB bands are taken for the evaluation and have been shown. The original images are presented as ground-truth and low-resolution images are down sampled from the ground-truth images since the lack of multi-resolution images of the same scene is not available. The sample images are shown in Figure 1.

The proposed work is compared with the existing methods such as PCA [2], IHS [3], wavelet [4], Brovey [6] and variation methods P+XS [8], and AVWP [9] and SIRF [10]. All simulations have been carried out using MATLAB. The evaluation results of the proposed work are compared with the previous existing research works that can be found in the literatures [2]–[4], [6], [8] - [10]. It is observed that PCA [2] performed the worst when the general intensities of the image are changed. Also it is noted that there exists no palpable relics are seen on the images produced by IHS [3] and Brovey [6].

Ground - Truth MS Pan PCA IHS Wavelet



Brovey P + XS AVWP SIRF

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Figure 1. Sample Imageset

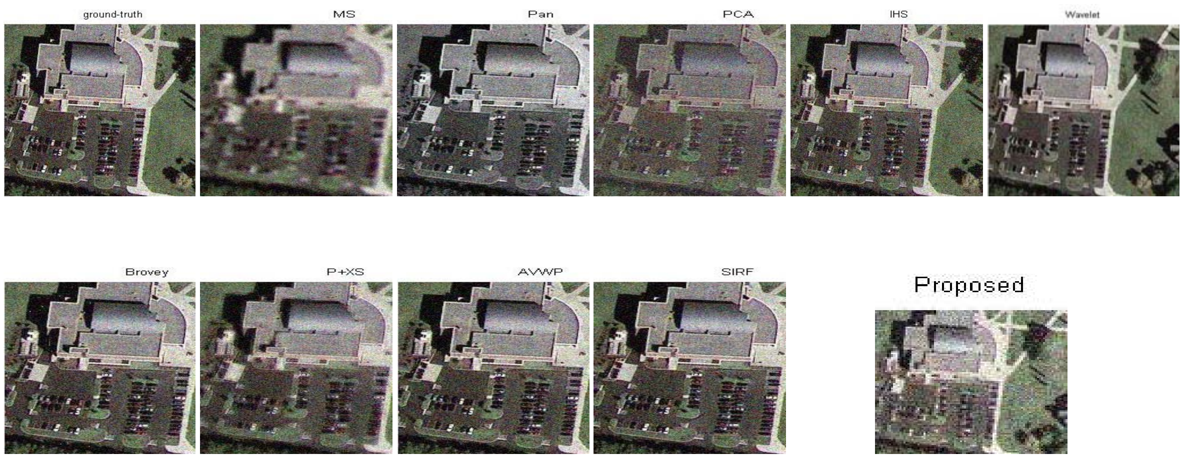

Figure 2. Gaussian Noise added Imageset

Noise added imageset is shown in Figure 2. On the other hand, a nearer glance depicts that the color on these images tends to change, especially on the trees and grass which is an indication of spectral distortion. Wavelet fusion [4] undergo spectral distortion and blocky artifacts. A blurred edge is a general issue in the image fused by P+XS [8]. AVWP [9] and SIRF [10] perform much better than all of them but it inherits the blocky artifacts of the wavelet fusion. Several test images of different sizes (ranges from 128 × 128 to 512 × 512) are cropped from Quickbird, Geoeye, IKONOS and SPOT datasets, which contain vegetation (e.g., forest, farmland), bodies of water (e.g., river, lake) and urban scenes (e.g., building, road). To evaluate the fusion quality of different methods, we used four metrics that measure spectral quality and one metric that measures spatial quality. The spectral metrics include the relative dimensionless global error in synthesis (ERGAS) [11], spectral angle mapper (SAM) [48], universal image quality index (Q-average) [12] and relative average spectral error (RASE) [13].

Ground - Truth MS Pan PCA IHS Wavelet

Brovey P + XS AVWP SIRF Proposed

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Figure 3. Noise Reduced Resultant Imageset

The filtered correlation coefficients (FCC) [4] were used as a spatial quality metric. Also, peak signal-to-noise ratio (PSNR), and root mean squared error (RMSE) and mean structural similarity (MSSIM) [49] were used to evaluate the accuracy when compared with the ground-truth. The results of variational methods [8], [9] have much lower values in ERGAS and RASE than those of conventional methods [2]–[4], [6]. From QAVE and SAM, the results are comparable to conventional methods. From all the above said observations it is concluded that these variational methods is capable enough to defend more spectral information. Due to the blurriness, P+XS has the worse spatial resolution in terms of FCC. In terms of error and similarity metrics (PSNR, MSSIM, RMSE), AVWP and P+XS are always the second best and second worst, respectively. Except for the same FCC as the wavelet fusion, our method is consistently better than all previous methods in terms of all metrics.

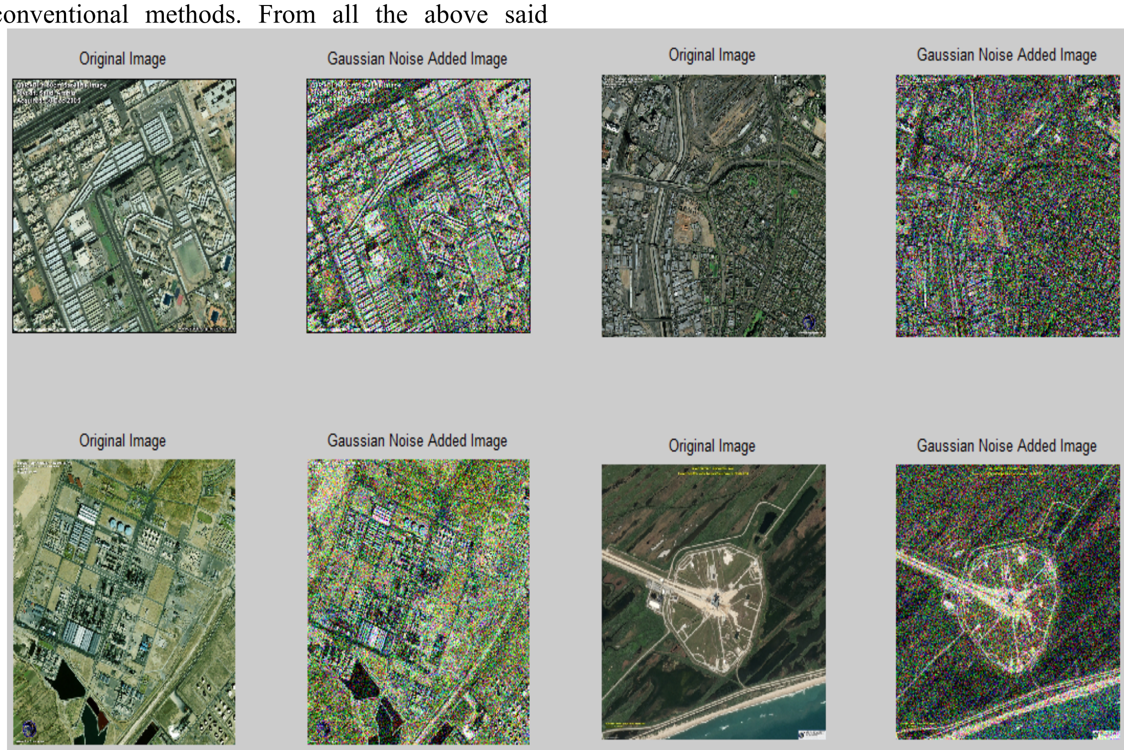

Figure 4. Noise added various Satellite Images

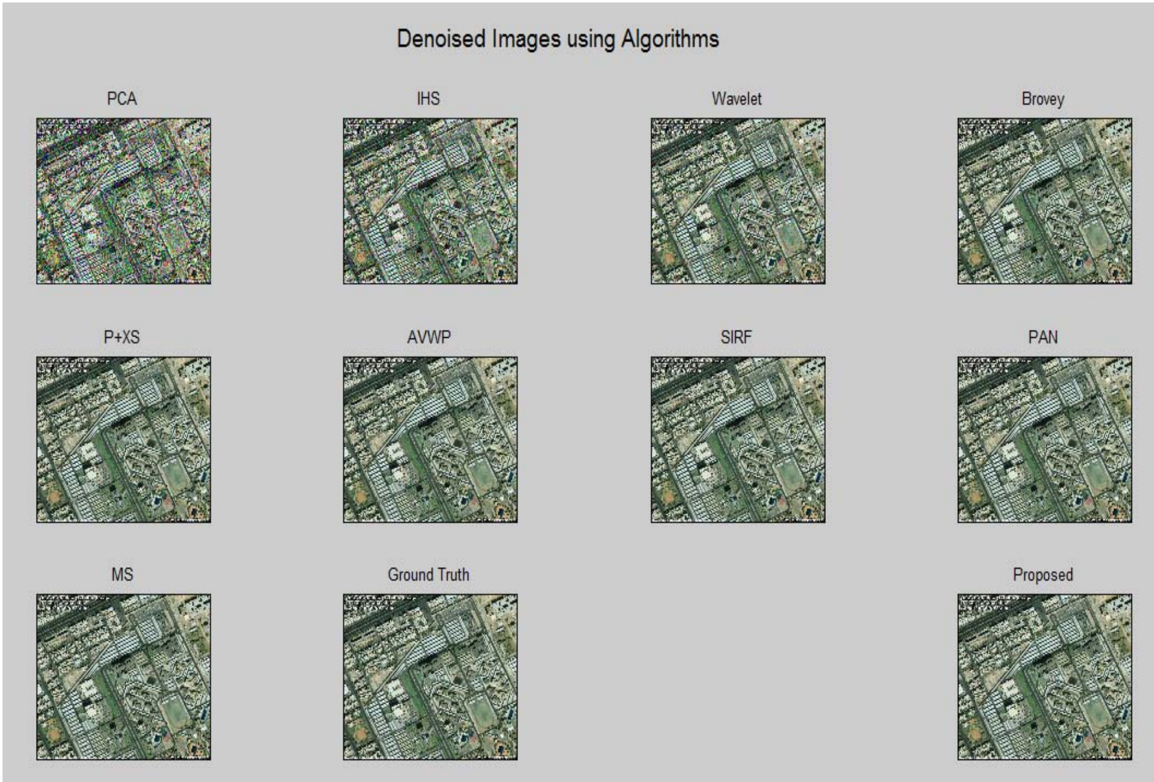

Figure 5. Denoised Satellite Image – 1

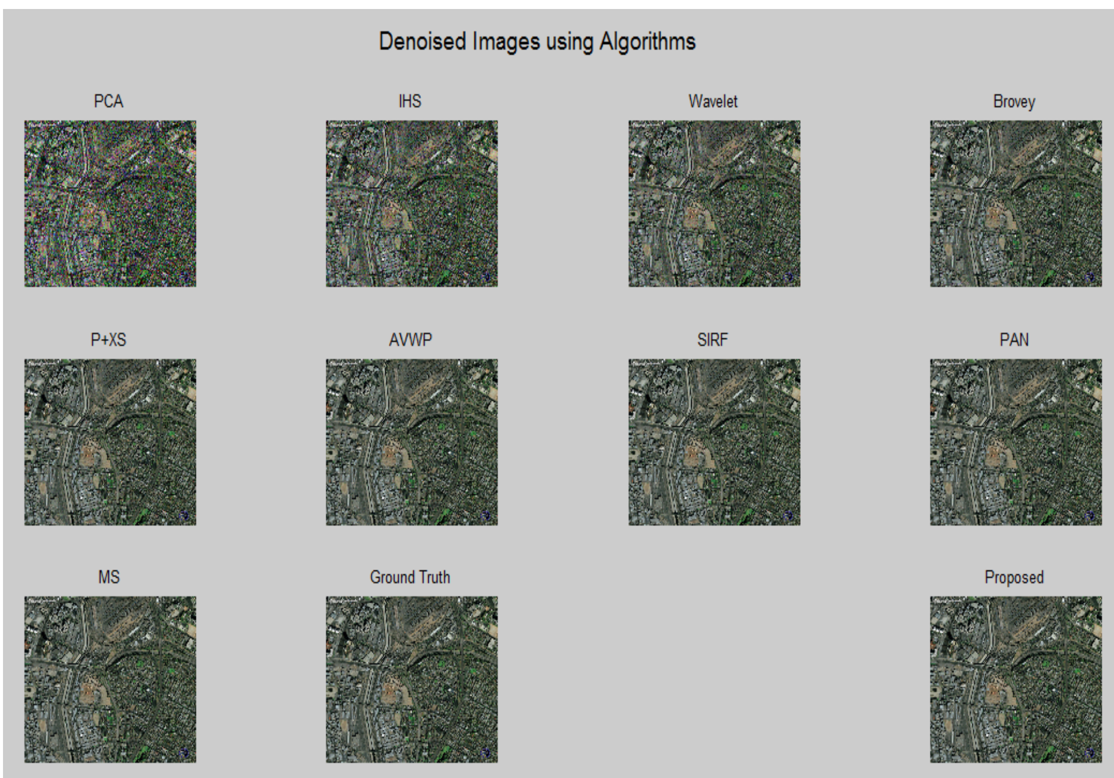

Figure 6. Denoised Satellite Image -2

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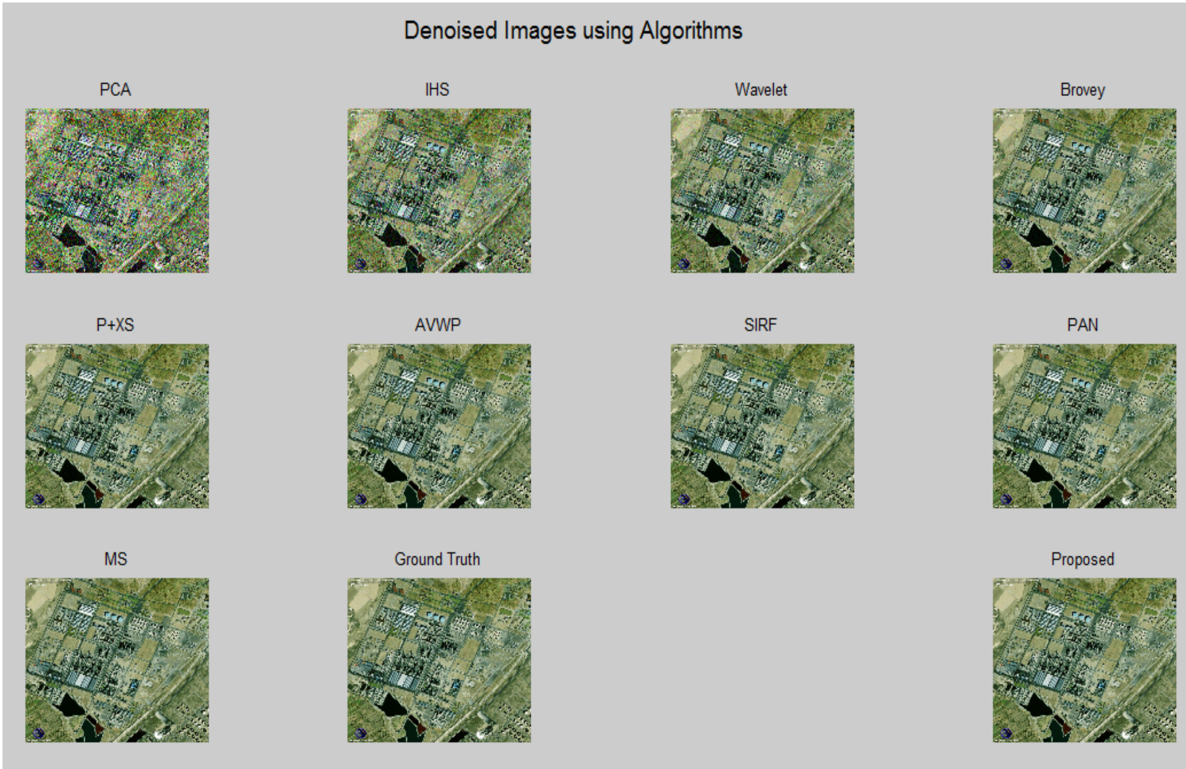

Figure 7. Denoised Satellite Image -3

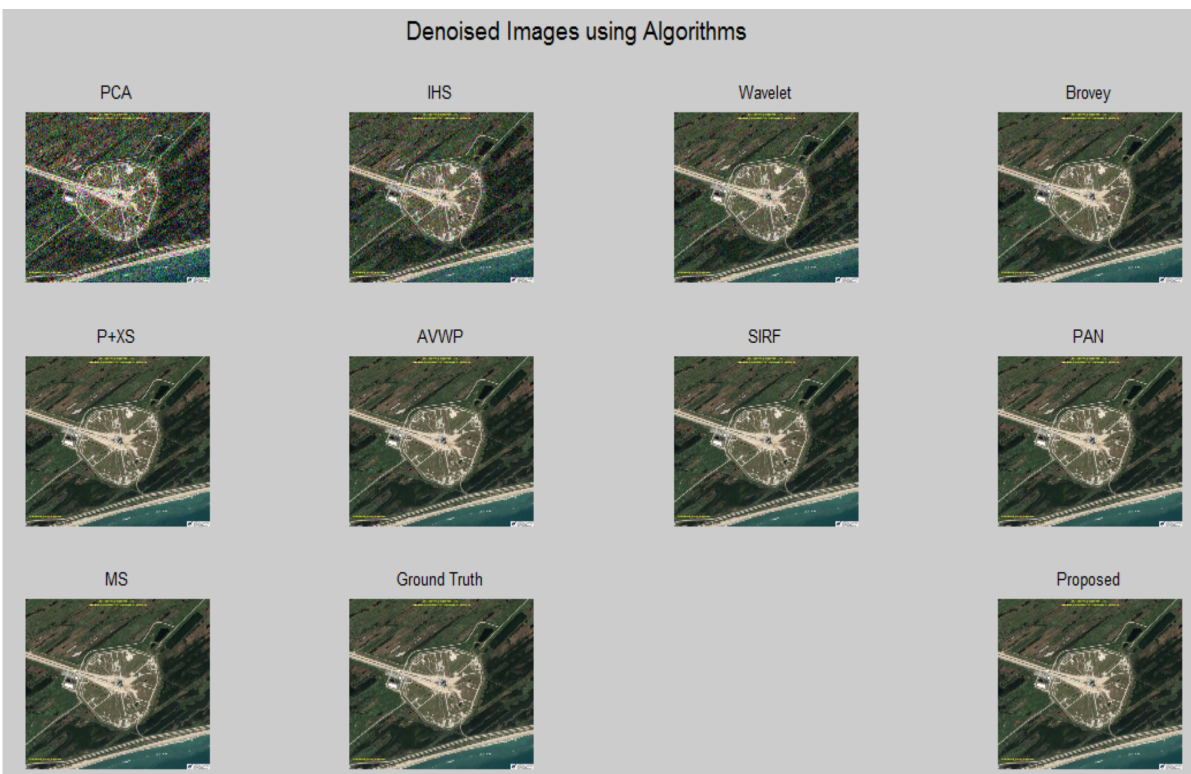

Figure 8. Denoised Satellite Image -4

Table 1. Performance Comparison on the Remotely Sensed Images

Method	*ERGAS*	*QAVE*	*RASE*	*SAM*	*FCC*	*PSNR*	*MSSIM*	*RMSE*
Desired Value	0	1	0	0	1	+ ∞	1	0
PCA [2]	5.67 ± 1.77	0.644 ± 0.055	22.3 ± 6.8	2.11 ± 1.35	0.972 ± 0.014	20.7 ± 2.7	0.799 ± 0.067	24.1 ± 6.7
IHS [3]	1.68 ± 0.86	0.734 ± 0.011	6.63 ± 3.4	0.79 ± 0.54	0.989 ± 0.006	31.2 ± 4.6	0.960 ± 0.035	8.1 ± 4.2
Wavelet [4]	1.18 ± 0.45	0.598 ± 0.113	4.50 ± 1.6	2.45 ± 1.18	0.997 ± 0.002	36.1 ± 3.6	0.983 ± 0.009	4.5 ± 1.9
Brovey [6]	1.22 ± 1.08	0.733 ± 0.011	5.18 ± 4.6	0.61 ± 0.58	0.940 ± 0.170	38.2 ± 5.6	0.989 ± 0.008	9.1 ± 19.7
P+XS [8]	0.89 ± 0.33	0.720 ± 0.036	3.47 ± 1.3	0.66 ± 0.36	0.898 ± 0.024	25.9 ± 3.5	0.854 ± 0.051	14.7 ± 5.4
AVWP [9]	0.46 ± 0.17	0.733 ± 0.013	1.81 ± 0.6	0.69 ± 0.70	0.996 ± 0.002	40.0 ± 3.5	0.991 ± 0.006	2.9 ± 1.0
SIRF [10]	0.07 ± 0.03	0.746 ± 0.004	0.3 ± 0.1	0.18 ± 0.11	0.997 ± 0.002	47.5 ± 3.6	0.998 ± 0.001	1.1 ± 0.5
Proposed Method	**0.06 ± 0.02**	**0.751 ± 0.003**	**0.28 ± 0.1**	**0.16 ± 0.12**	**0.997 ± 0.001**	**48.6 ± 3.2**	**0.997 ± 0.001**	**1.0 ± 0.4**

Gaussian noise is added to four other satellite images and has been shown in the Figure.4. The existing 10 algorithms are compared with the proposed fuzzy based mechanism and have been presented in the Figure5, Figure 6, Figure 7 and Figure 8. The overall performance of the proposed work is presented in Figure 9.

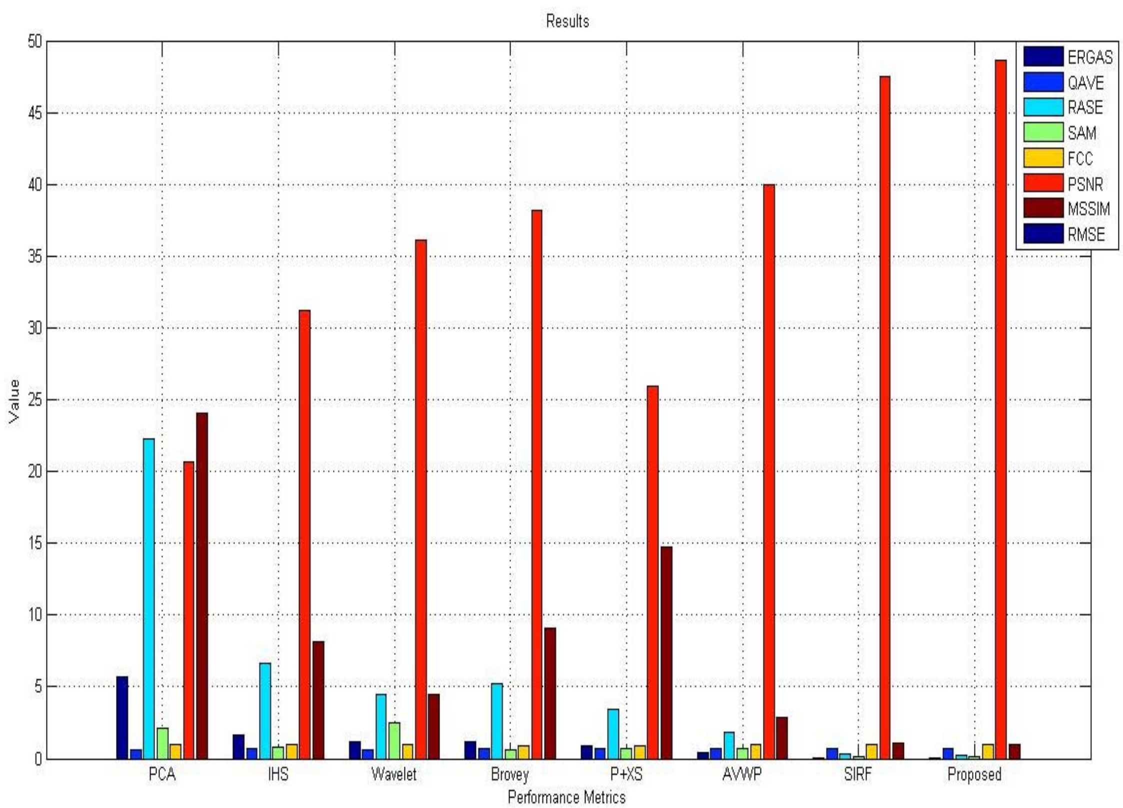

Figure 9. Comparative Analysis of the Proposed Work with Existing Works

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5. CONCLUSIONS

This research work aims in noise reduction by applying techniques such as fuzzy based noise removal, pixel classification, restoration and filtering. The proposed work is compared with several existing approaches such as PCA, IHS, Wavelet, Brovey, P + XS, AVWP and SIRF. Simulations are carried out using MATLAB and the metrics such as ERGAS, QAVE, RASE, SAM, FCC, PSNR, MSSIM and RMSE are chosen for evaluating the performance of the proposed work. It is significant that by making use of fuzzy logic technique the obtained results shows better performance in terms of chosen metrics.

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