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Performance Analysis of Enhancement Techniques for Satellite Images

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Abstract— **Satellite image processing is one of the important research areas in the field of digital image processing and is a challenging task for the researchers. It is often required to remove noise and smooth the image to highlight certain features of interest for image analysis and extracting significant information from satellite images often termed as image enhancement. It is an important step for overall image recognition and interpretation process and is a pre processing step that serves as an important step towards the solution for image analysis. Image enhancement can be performed in spatial or frequency domains. In this paper, we focus on spatial domain enhancement techniques with respect to satellite images. Some of the important image enhancement techniques such as contrast stretching, decorrelation stretch, histogram equalization and contrast limited adaptive histogram equalization are experimented and compared for visual interpretability. Two parameters, Mean Squared Error (MSE) and Peak Signal to Noise Ratio (PSNR) are used for performance evaluation. The techniques are tested using 20 LandSat satellite images with different illumination effects. The experimentation was carried out using soft computing tool Matlab. It was observed that for satellite images, contrast stretching gives better results as compared to other techniques.**

Keywords- Image Enhancement; Contrast Stretching; Mean Squared Error (MSE); Peak Signal to Noise ratio (PSNR); Landsat Imagery

I. INTRODUCTION

Digital image processing is an important research area that makes use of computer algorithms for analysis and interpretation of digital images. Image enhancement is one of the important phases of overall image recognition and interpretation process. It is the pre processing step that serves as an important step towards the solution for image analysis. It refers to the techniques used for improving the interpretability or perception of information in any image by increasing the distinction between the features of the image. Image enhancement particularly finds its importance in the field of analysis of medical images, aerial and satellite images, surveillance systems, astronomy, industrial applications, forensics etc.

In image enhancement, an image is manipulated so that the result is more suitable than the original for any specific purpose. The enhancement may be carried out either in spatial domain or frequency domain. Frequency domain enhancement methods perform modification on Fourier transformation of the original image where as in spatial domain enhancement methods the pixels in an image are directly manipulated. Spatial feature manipulations are normally local operations where the central pixel values are calculated with respect to their neighbourhood pixels. Filtering techniques and edge enhancement are some of the local operations for image enhancement.

In case of remotely sensed images, images are captured without physical contact with ground surface. A number of different sensors are used to capture the images over various regions. Such images include satellite and aerial images and these images prove useful in the fields such as determining land use patterns, environmental analysis, weather forecasting, vegetation monitoring and other related areas. Image enhancement is often required for satellite images in order to identify the objects and extract features and their coordinates from images. A number of methods are available for image enhancement such as contrast stretching, histogram equalization, decorrelation stretch, contrast-limited adaptive histogram equalization, convolution, linear and non-linear filters. Keeping in view the complexities of satellite images, the selection of suitable technique for image processing may differ from one application to another. There is very less work performed using these techniques for satellite and aerial images but choosing a suitable enhancement technique is a difficult task.

There is a need to assess the quality of enhanced images. A number of measures are available for checking the performance of enhancement methods. In this paper, two measures, namely, Mean Squared Error (MSE) and Peak Signal to Noise Ratio (PSNR) are used.

For satellite images, there are a number of databases available but Landsat is used for this research work. Landsat is a remote-sensing satellite program operated by National Aeronautics and Space Administration (NASA). It is an ongoing series of satellites that conduct Earth observations. The purpose of Landsat is to gather facts about natural resources of our planet and consistently archive images of earth. The sensors used in Landsat have moderate spatial resolution and provide valuable images of our planet. Though individual small elements may not be visible in these images but large structures are clearly visible for analysis and interpretation.

Landsat data has been used to support wide range of applications and is used by government, commercial, industrial and educational communities throughout the world. The application areas include research, agriculture, change detection, forestry, mining and many more to mention. For performance analysis of enhancement techniques, a set of 20 satellite images were downloaded from Landsat image gallery.

This paper presents performance analysis of enhancement techniques for satellite images and is organized in five sections. Section I provides brief introduction about the image enhancement techniques with respect to satellite images and section II summarizes the literature review on various enhancement methods. Section III describes some of the image enhancement techniques used for satellite images. Experimentation and results using Landsat images are presented in section IV and concluding remarks are given in section V.

II. LITERATURE REVIEW

Image enhancement is a technique in digital image processing which increases the separability among the features in the scene. It is considered as middle level processing step which increase the amount of details that can be interpreted from data. Enhancement is also problem oriented. For example, the technique useful for enhancing X-ray images may not be suitable in context of satellite images.

Singh et al. presented a critical review on various image enhancement techniques and evaluated different techniques in spatial and frequency domains and discussed their advantages and disadvantages [1]. A qualitative comparative study of various contrast enhancement techniques such as linear stretch, histogram equalization, convolution mask enhancement was performed and comparative analysis of various quality factors such as MSE, NAE, PSNR etc was done [2].

Lisani et al. presented a review on commonly used algorithms for contrast enhancement and tone mapping and tested using specific cases of satellite images such as shadowed and bright image regions. Both color images as well as grayscale images were used for enhancement of image brightness [3]. Shaikh et al. developed a simulation model in Matlab to study the effect of filtering techniques. They used linear and non-linear filtering techniques for image enhancement. The authors used non-linear filter for noise removal and histogram equalization for image enhancement. It was proved that median filter perform better than other filtering techniques and it works well for noise removal as well as to remove blurred effect in an image [4].

A comparison between different image enhancement techniques using MSE and PSNR quality parameters was carried out. Kaushik et al. proposed a new enhancement technique using erosion [5]. Kumar discussed image enhancement and information extraction techniques and their role in analysis and interpretation of remotely sensed images [6].

Aedla et al. proposed a new contrast enhancement technique based on plateau histogram equalization. The image was decomposed using Bi-Histogram Equalization with Plateau Limit and threshold calculation was done using Self-Adaptive Plateau Histogram Equalization. The comparison was done with other histogram equalization based techniques using image quality measures like Absolute Mean Brightness Error (AMBE) and Peak Signal to Noise Ratio (PSNR) [7].

Al-amri et al. presented the study of linear and non-linear contrast enhancement techniques. Max-min, percentage and piecewise contrast enhancement techniques were applied in the category of linear contrast enhancement techniques. Non-linear techniques included histogram equalization, adaptive histogram equalization, homomorphic filter and unsharp mask [8].

Attachoo et al. presented a new method of image filtering to enhance details and sharpen the edges of satellite images. The authors used histogram equalization along with filtering process consisting of convolution and sharpening with Laplacian for 3 color bands to get a sharpened and clear satellite image. Statistical index and signal to noise ratio of true color and false color of histogram equalization were used for analysis. The multispectral satellite image was converted into a composite color image and then convolved with the help of Laplacian technique [9].

Satellite image enhancement based on interpolation of high-frequency sub bands was obtained by discrete wavelet transform (DWT). Inverse DWT was used to reconstruct the resultant image and the results were illustrated using Landsat image. Image quality with respect to resolution as well as contrast enhancement was done. Gray level, color and satellite images were used for experimentation and the comparative analysis was carried out using PSNR, mean and deviation and computational complexity [10],[11],[12],[13]. A technique called Multi-Decomposition Histogram Equalization was presented in order to preserve contrast and brightness in images by decomposing input image into subimages and then performing classical histogram equalization to each subimage and then interpolating them in correct order. Various parameters like PSNR, SNR, RMSE, MSE were used for comparative analysis of techniques [14].

Sun et al. presented a spectral resolution enhancement method for remotely sensed multispectral images. A comparison was done between spectra-enhanced and real data in the overlapped regions with the help of statistical analysis and classification application [15].

Singh and Dixit compared three methods of image enhancement namely histogram equalization, dynamic histogram equalization, contrast limited adaptive histogram equalization. The authors focused on contrast enhancement of digital images for applications like biometric analysis, pattern identification etc. Original and enhanced images were compared using PSNR and NAE (Normalized Absolute Error) [16]. Syrris et. al. investigated the sensitivity of contrast-based textural measurements and morphological characteristics as a result of various image enhancement techniques. The authors present the case study for testing a mixture of image enhancement operations such as linear and decorrelation stretching. Results demonstrated that contrast adjustment of grayscale images are based on spectral band combination [17].

Vashisth and Sharma presented a survey of a number of enhancement methods for different types of images. The authors compared spatial domain methods like median filtering, averaging filtering and histogram equalization [18].

III. ENHANCEMENT TECHNIQUES FOR SATELLITE IMAGES

A number of image enhancement techniques such as linear and non-linear filters, histogram equalization, contrast stretching, decorrelation stretch, contrast-limited adaptive histogram equalization are available. A brief description about a few of them is given in the following section.

1. Contrast Stretching

Contrast stretching adjusts the local contrast in the different regions of the image so that details corressponding to light and dark areas are more highlighted with fine details and displays image with improved contrast. Contrast stretching expands the range of intensity levels in an image so that it spans the dynamic intensity range of the recording medium or the display device. It darkens pixels below particular intensity level and brightens pixels above that intensity level in the original image. The types of transform function results either in linear or non-linear contrast stretch. For example, linear contrast stretch uses a linear thresholding function

$$s = T(r) \quad (1)$$

where *s* and *r* respectively denote intensity values of output and input at any image position (x,y).

In non-linear contrast stretching, the digital numbers are not expanded to fill entire intensity range of display device, rather they use non-liner transform functions such as histogram-equalized, piece-wise or logarithmic/Guassian stretch.

2. Decorrelation Stretch

Decorrelation stretch enhances the color separation in an image. It tends to decrease the correlation between different bands of an image. The original color values of the image are mapped to a new set of color values with a wider range. This technique is normally applied to 3 band images (ordinary RGB images or RGB multispectral composite images). The separation in color intensities improves visual interpretation and makes feature discrimination easy.

3. Histogram Equalization

Histograms are the basis for a number of spatial domain processing techniques. Histogram Equalization is one of these techniques which enhance contrast of images by transforming the values in an intensity image so that the histogram of the output image approximately matches a specified histogram which can be flat, bell-shaped or curved. The intensity levels in an image may be viewed as random variables in the interval [0,*L*-1]. It uses a linear transformation

$$s_k = T(r_k) = \frac{(L-1)}{MN}\sum_{j=0}^{k} n_j \quad (2)$$

where r_k and s_k represents intensity levels in input and output images respectively and MN denotes the total number of pixels in the input image. A processed image is obtained by mapping each pixel in the input image with intensity r_k into a corresponding pixel with level s_k in the output image.

4. Contrast-limited adaptive histogram equalization (CLAHE)

CLAHE is a technique that operates on small blocks of the image instead of operating on the entire image. Each block is processed separately for contrast enhancement. CLAHE was basically used for enhancing low-contrast images in the field of medical imaging but it also serves as an effective enhancement method for low contrast satellite images. It works by matching the histogram of the output image with the one specified by the distribution type which can be set to flat, bell-shaped or curved histogram. This technique works well for grayscale and color images but there is high variation in the colors of original and enhanced images.

5. Convolution

Convolution is a general purpose linear filter where the values of central pixel are calculated as weighted average of neighboring pixels. It involves a mathematical operation comprised of integers and is used to modify the spatial frequency characteristics of an image. It is useful for getting effects such as blurring, sharpening, edge detection etc. For edge handling, convolution requires additional pixels which may be the repetition of image boundaries usually edge or corner pixels. Convolution is commutative, associative and distributive in nature and can be performed either in spatial or frequency domains.

6. Median Filter

The median filter is a commonly used non-linear digital filtering technique. It is often used as a pre processing step for noise removal in order to improve results of further analysis. It also preserves edges while removing noise which is crucial to visual appearance of images. In this technique, the central pixel values are calculated as median of its neighboring pixels.

IV. Experimentation and Results

The above mentioned image enhancement techniques were implemented and tested. A set of twenty Landsat images were downloaded and resized to 256*176 pixels. These images consisted of water and land views and were enhanced. For histogram equalization and CLAHE, the satellite images were processed by separating R, G and B components. RGB component images are grayscale images. After processing, the resultant images were combined together to generate the final enhanced image. Fig. 1 shows the results of enhancement techniques performed on five out of twenty images. It shows original and enhanced images obtained as a result of performing image enhancement.

For image enhancement techniques, the soft computing tool Matlab was used. Some of the functions from Image Processing Toolbox such as stretchlim, imadjust and histeq were used. For contrast stretching, stretchlim function finds limits for stretching contrast based on intensity range of display device. For color images, it returns intensity pairs to saturate each plane of RGB image. The saturation values can also be specified manually. imadjust adjusts image intensity values according to values given by stretchlim function.

In fig. 1, column 1 shows the original images and columns 2, 3, 4 and 5 show enhanced images obtained as a result of CLAHE, decorrelation stretch, histogram equalization and contrast stretching respectively.

Table 1 shows the MSE values obtained using different techniques. For example, in column 5, using contrast stretching, the first image shows MSE value of **0.0379** and it is **0.0053** for fifth image. Similarly, the other columns show MSE values obtained using other techniques for a set of five images obtained from LandSat database.

Table 2 shows the PSNR values obtained using different techniques. For example, in column 5, using contrast stretching, the first image shows PSNR value of **62.3470** and it is **70.9049** for fifth image. Similarly, the other columns show PSNR values obtained using other techniques.

Other techniques like convolution, mean and median filters were also explored but the results did not show much difference between original and enhanced images.

TABLE I. MEAN SQUARED ERROR

Image	MSE obtained using CLAHE(on separate RGB channels)	MSE obtained using Decorrelation Stretching	MSE obtained using Histogram Equalization	MSE obtained using Contrast Stretching
1	0.0502	**0.0379**	0.1184	**0.0379**
2	0.0395	0.0573	0.0571	**0.0173**
3	**0.0186**	0.0432	0.0414	0.0206
4	**0.0256**	0.0492	0.1030	0.0484
5	0.0512	0.0277	0.1407	**0.0053**

TABLE II. PEAK SIGNAL TO NOISE RATIO

Image	PSNR obtained using CLAHE(on separate RGB channels)	PSNR obtained using Decorrelation Stretching	PSNR obtained using Histogram Equalization	PSNR obtained using Contrast Stretching
1	61.1219	62.3423	57.3961	**62.3470**
2	62.1654	60.5529	60.5608	**65.7418**
3	**65.4275**	61.7748	61.9602	64.9944
4	**64.0492**	61.2084	58.0015	61.2813
5	61.0363	63.7004	56.6484	**70.9049**

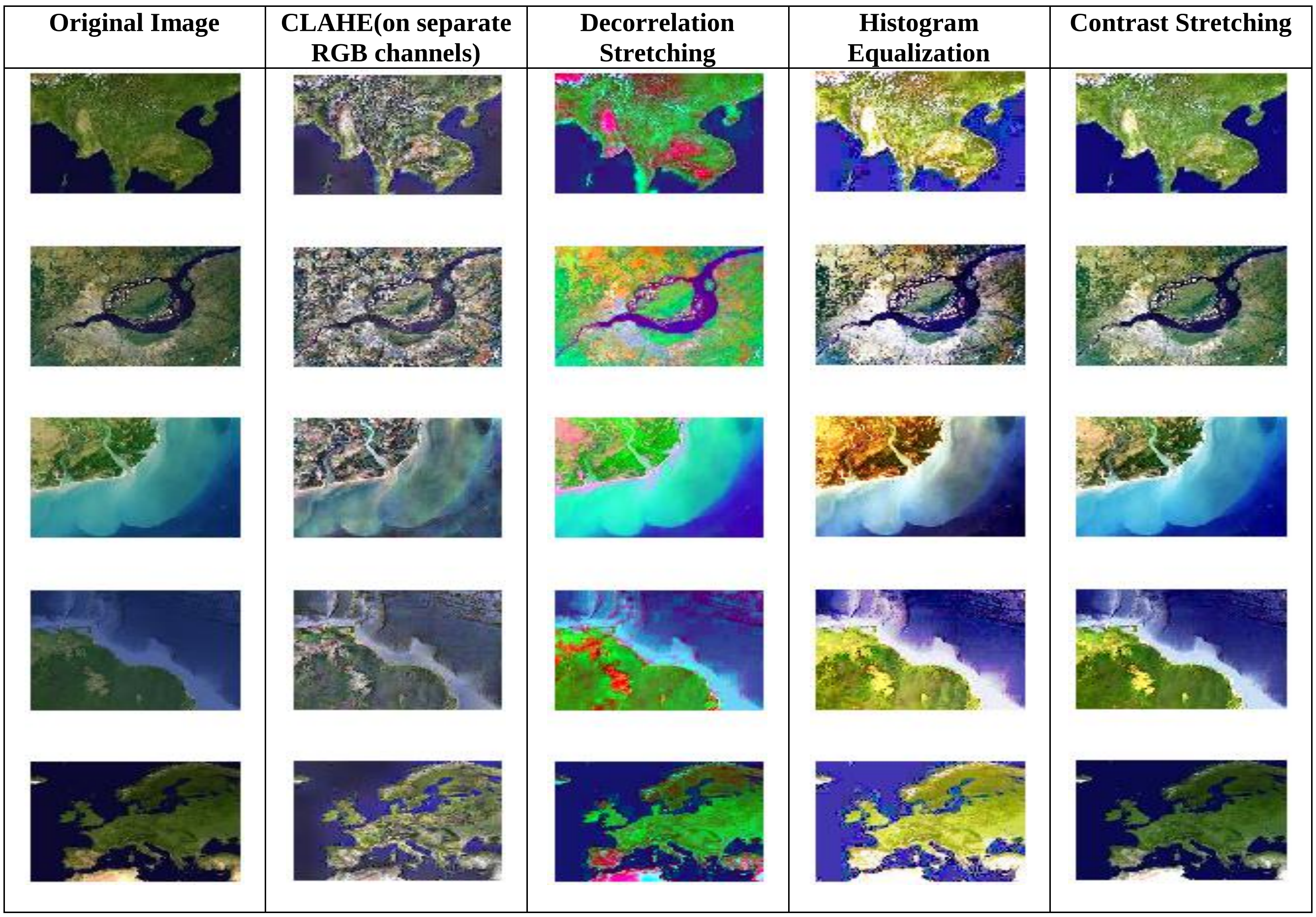

Figure 1. Original and enhanced images

This research presented a comparison between five image enhancement techniques namely, CLAHE (with separate processing for RGB channels), Decorrelation Stretch, Histogram Equalization and Contrast Stretching. The experiments were performed on 20 satellite images with varying illumination and contrast conditions downloaded from Landsat database. The results obtained from Contrast Stretching yielded a better quality image as compared to other techniques.

V. CONCLUSION AND SCOPE FOR FUTURE WORK

A number of enhancement techniques were explored and performance analysis was carried out based on parameters MSE and PSNR using LandSat images. It is very important to select a suitable enhancement technique for satellite images. It is concluded that in spatial domain image enhancement techniques, contrast stretching is an effective method for satellite images. Also, the mentioned techniques are effective in improving the visual interpretability level in satellite images. Image enhancement techniques for satellite images can be applied in frequency domain also. The applied enhancement techniques can be tested using other databases such as Google Earth, QuickBird, IKONOS.

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