

Brightness and Resolution Enhancement of Satellite Images using SVD and DWT

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Abstract— A new satellite image resolution and brightness enhancement technique based on the discrete wavelet transform (DWT) and singular value decomposition (SVD) has been proposed. Satellite images are used in many applications such as geosciences studies, astronomy, and geographical information systems. One of the most important quality factors in images comes from its resolution. The technique decomposes the input image into the four frequency sub-bands by using DWT and estimates the singular value matrix of the low-low sub band image, and, then, it reconstructs the enhanced image by applying inverse DWT. The technique also estimates the singular value matrix of the low-low sub band of histogram equalized image and normalize both singular value matrices to obtain brightness enhanced image. The technique is compared with conventional image equalization techniques such as standard general histogram equalization and local histogram equalization, as well as state-of-the-art techniques such as brightness preserving dynamic histogram equalization and singular value equalization. The experimental results show the superiority of the proposed method over conventional and state-of-the-art technique.

Keywords— Bicubic interpolation, discrete wavelet transform (DWT), mean square error (MSE), peak signal to noise ratio (PSNR), satellite resolution enhancement, satellite brightness enhancement, singular value decomposition (SVD).

I. INTRODUCTION

The principal objective of enhancement is to process an image so that the result is more suitable than the original image for a specific application. Image enhancement is one of the most interesting and visually appealing areas of image processing. Image enhancement approaches fall into two broad categories: spatial domain methods and frequency domain methods. The term spatial domain refers to the image plane itself, and approaches in this category are based on direct manipulation of pixels in an image. Frequency domain processing techniques are based on modifying the Fourier transform of an image. Enhancement techniques based on various combinations of methods from these two categories are not unusual. There is no general theory of image enhancement. When an image is

processed for visual interpretation, the viewer is the ultimate judge of how well a particular method works.

Resolution of an image has been always an important issue in many image- and video-processing applications, such as video resolution enhancement [1], feature extraction [2], and satellite image resolution enhancement [3].

Interpolation in image processing is a method to increase the number of pixels in a digital image. Interpolation has been widely used in many image processing applications, such as facial reconstruction [4], multiple description coding [5], and image resolution enhancement [6]–[8]. The interpolation-based image resolution enhancement has been used for a long time and many interpolation techniques have been developed to increase the quality of this task.

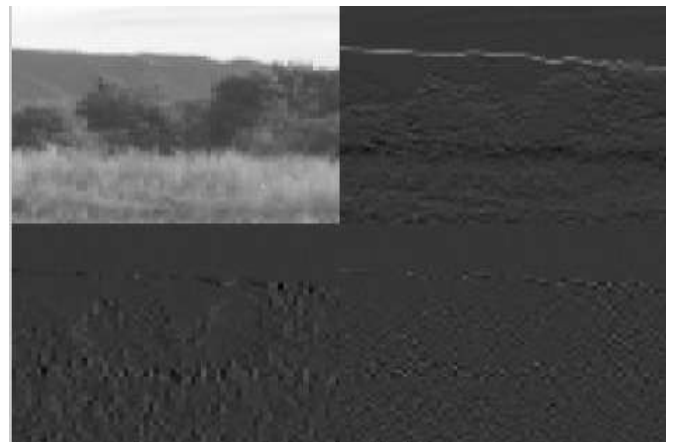


Figure 1: LL, LH, HL and HH sub bands of a satellite image obtained by using DWT

Wavelets are also playing a significant role in many image processing applications. The 2-D wavelet decomposition of an image is performed by applying the 1-D discrete wavelet transform (DWT) along the rows of the image first, and then the results are decomposed along the columns. This operation results in four decomposed sub-band images referred to low-low (LL), low-high (LH), high-low (HL), and high-high (HH). The frequency components of those sub-bands cover the full frequency spectrum of the original image.

In this paper, we propose a resolution-enhancement technique using interpolated DWT high-frequency sub-band images and the input low-resolution image. Inverse DWT (IDWT) has been applied to combine all these images to generate the final resolution-enhanced image. In order to achieve a sharper image, we propose to use an intermediate stage for estimating the high frequency sub-bands by utilizing the difference image obtained by subtracting the input image and its interpolated LL sub-band [17]. We also propose a brightness enhancement technique using SVD method on low frequency sub-band of both input and histogram equalised images. The proposed technique has been compared with standard interpolation techniques, wavelet zero padding (WZP), where the unknown coefficients in high-frequency sub-bands are replaced with zeros, and state-of-art techniques, such as WZP and cycle spinning (CS) [17], and previously introduced complex wavelet transform (CWT)-based image resolution enhancement [3].

The paper is organized as follows. Section II gives an overview on the state-of-art image resolution enhancement techniques used for comparison purposes. Section III introduces the proposed wavelet based resolution and brightness enhancement technique. Section IV discusses the qualitative and quantitative results of the proposed method with the conventional and state-of-art resolution enhancement techniques. Conclusions are given in the final section.

II. EXISTING METHODS

There are several methods which have been used for satellite image resolution enhancement. In this paper, we have used two state-of-art techniques for comparison purposes. The first one is WZP and CS [18], and the second one is the previously introduced CWT-based image resolution enhancement [3].

A. CS Based Image Resolution Enhancement

This method adopts the CS methodology in the wavelet domain [15]. The algorithm consists of two main steps as follows:

- 1) An initial approximation to the unknown high resolution image is generated using wavelet domain zero padding (WZP).
- 2) The cycle-spinning methodology is adopted to operate the following tasks:
 - (a) A number of low resolution images are generated from the obtained estimated high resolution image in part (1) by spatial shifting, wavelet transforming, and discarding the high frequency sub bands.
 - (b) The WZP processing is applied to all those low resolution images yielding N high resolution images.
 - (c) These intermediated high resolution images are realigned and averaged to give the final high resolution reconstructed image [18].

B. CWT-Based Image Resolution Enhancement

In this technique, dual-tree CWT (DT-CWT) is used to decompose an input image into different sub band images. DT-CWT is used to decompose an input low-resolution image into different sub bands. Then, the high-frequency sub band images and the input image are interpolated, followed by combining all these images to generate a new high-resolution image by using inverse DT-CWT. The resolution enhancement is achieved by using directional selectivity provided by the CWT, where the high-frequency sub bands in six different directions contribute to the sharpness of the high-frequency details, such as edges [18].

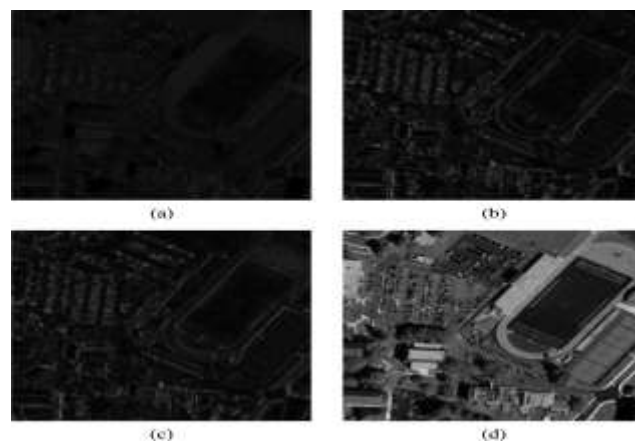


Figure 2: Difference between (d) the original high-resolution satellite image and (a) the proposed enhanced image, (b) the standard bicubic interpolation, and (c) the WZP- and CS-based image resolution enhancement technique [18].

III. PRESENT INVESTIGATION

The aim of this work is to enhance the resolution and brightness of low resolution satellite images using DWT (Discrete Wavelet Transform) and SVD (Singular Value Decomposition) transform. The DWT technique enhances the resolution of the satellite image whereas the SVD technique enhances the brightness of the satellite image. This work leads to more clarity for the output image compared with the input image. The enhancement is measured in terms of PSNR (Peak Signal to Noise Ratio) values and MSE (Mean Square Error) values of both input and output images. An increase in PSNR value indicates resolution enhancement. These values are the basis for quantitative analysis.

We consider a high frequency low resolution satellite image as input. Apply histogram to this input image (GHE). Histogram equalization is a process of automatically determining transformation function which produces an output image with a uniform histogram.

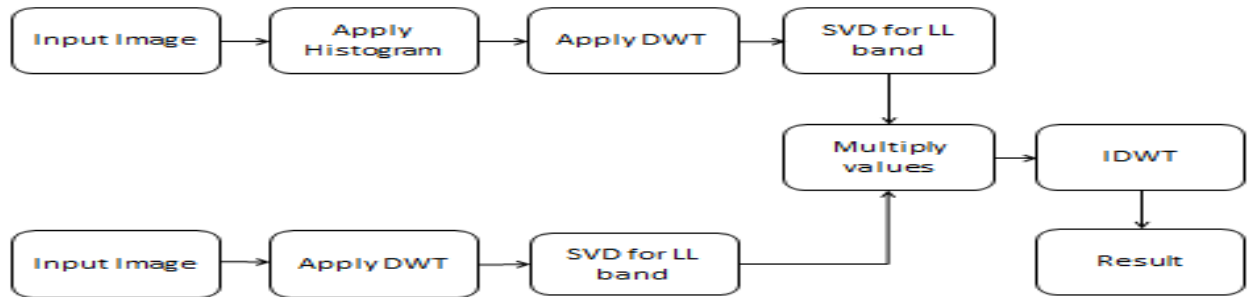


Figure 3: Block diagram of proposed brightness and resolution enhancement algorithm

Then apply DWT to GHE image and input image, say, image 1 and image 2 respectively. In wavelet decomposing of an image, the decomposition is done row by row and then column by column. Thus by DWT process the image will be subdivided into four bands. Of the four sub images obtained the one obtained by low-pass filtering the rows and columns is referred to as the LL image. The one obtained by low-pass filtering the rows and high-pass filtering the columns is referred to as the LH images. The one obtained by high-pass filtering the rows and low-pass filtering the columns is called the HL image. The sub image obtained by high pass filtering the rows and columns is referred to as the HH image. We use lifting scheme as intermediate stage in DWT process.

Consider the LL image among the four images. Then apply SVD to the LL band image of image 1 and image 2. By singular value decomposition of an $m \times n$ real or complex matrix M is a factorization of the form:

$$M = U \Sigma V^* \quad (1)$$

where U is an $m \times m$ real or complex unitary matrix, Σ is an $m \times n$ rectangular diagonal matrix with nonnegative real numbers on the diagonal, and V^* (the conjugate transpose of V) is an $n \times n$ real or complex unitary matrix.

Output is then combined by multiplying the values of image 1 and image 2 after application of SVD on both images. Then we apply IDWT (Inverse DWT) technique. IDWT has been applied to combine all these images to generate the final resolution-enhanced image. In order to achieve a sharper image, we propose to use an intermediate stage for estimating the high frequency sub bands by utilizing the difference image obtained by subtracting the input image and its interpolated LL sub band.

The output of IDWT process gives Brightness and Resolution enhanced image due to the application of DWT and SVD technique in the earlier stage of this enhancement process.

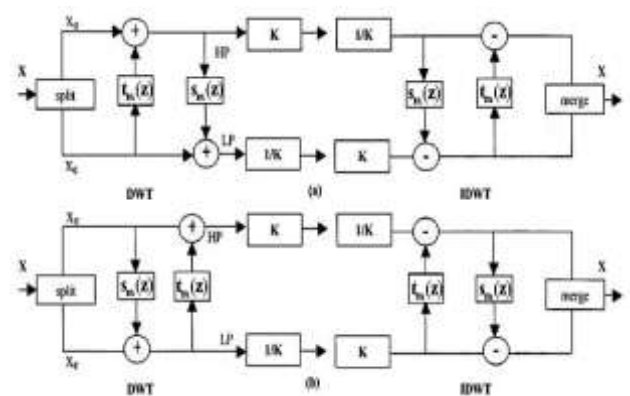


Figure 4: Lifting Scheme (a) Forward Transform, (b) Inverse Transform

IV. RESULTS AND DISCUSSIONS

The proposed technique has been tested on several different satellite images. In order to show the superiority of the proposed method over the conventional and state-of-art techniques from visual point of view, figures. 6-7 are included. In those figures with low-resolution satellite images, the enhanced images by using bicubic interpolation, enhanced images by using WZP and CS-based image resolution enhancement, and also the enhanced images obtained by the proposed technique are shown. It is clear that the resultant image, enhanced by using the proposed technique, is sharper than the other techniques [18].

Figure 6 shows that a satellite image in (e) enhanced by using the proposed technique is clearly sharper than the low resolution input image in (a) and (b), as well as the interpolated image in (c) and enhanced image by WZP and CS technique in (d).

Not only visual comparison but also quantitative comparisons are confirming the superiority of the proposed method. Peak signal-to-noise ratio (PSNR) and root mean

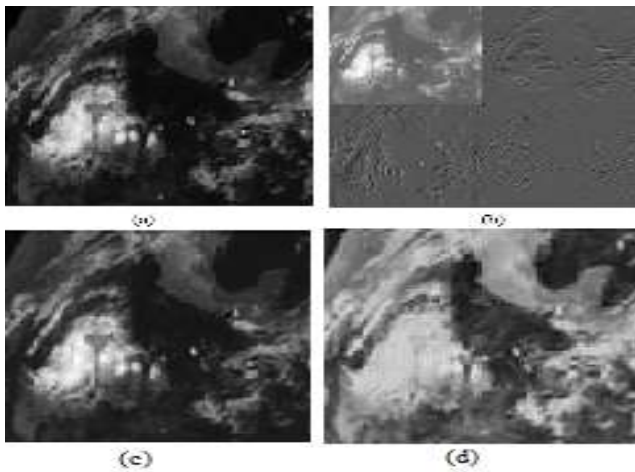


Figure 5: (a) Input image, (b) DWT applied image,(c) Resolution enhanced Image, (d) Brightness enhanced image

square error (RMSE) have been implemented in order to obtain some quantitative results for comparison. PSNR can be obtained by using the following formula ;

$$PSNR = 10 \log_{10} \left(\frac{R^2}{MSE} \right) \quad (2)$$

where R is the maximum fluctuation in the input image (255 in here as the images are represented by 8 bit, i.e., 8 bit gray scale representation have been used—radiometric resolution is 8 bit); and MSE is representing the MSE between the given input image I_{in} and the original image I_{org} which can be obtained by the following:

$$MSE = \frac{\sum_{i,j} (I_{in}(i,j) - I_{org}(i,j))^2}{M \times N} \quad (3)$$

where M and N are the size of the images.

Clearly, RMSE is the square root of MSE, hence it can be calculated by the following:

$$RMSE = \sqrt{\frac{\sum_{i,j} (I_{in}(i,j) - I_{org}(i,j))^2}{M \times N}} \quad (4)$$

Table 1 is showing the comparison between the proposed method using Daubechies (db.9/7) wavelet transform with bilinear interpolation and some state-of-art resolution enhancement techniques, such as WZP, WZP and CS super-resolution technique and also the formerly proposed resolution enhancement technique by means of calculating PSNR. Table 2 is showing the comparison between the proposed method using Daubechies (db.9/7) wavelet transform with bilinear interpolation and aforementioned conventional and state-of-art techniques by means of RMSE. The results in Table 2 are correlated with

the results in Table 1, which is expected due to the definition of the PSNR in (2). Overall, the results in Tables1 and 2 show that the proposed method over performs the aforementioned state-of-art and conventional techniques.

In order to show the improvement obtained by the proposed satellite image resolution enhancement from information content point of view, the entropy of Figures 6 (1) and (2) and 7 (1) and (2) have been calculated. Table 3 is showing these entropy values.

As expected, highest level of information content is embedded in the original images. The main reason of having the relatively high information content level of the images generated by the proposed method is due to the fact that the un-quantized input LL-sub band images contain most of the information of the original high-resolution image. A possible unsigned 8-bit representation of the LL-sub band image would introduce irreversible quantization loss of information which is given in the first row of Table 3.

The application of SVD transform to the LL image obtained from DWT process increases the brightness of the image which is confirmed from the figure 7.

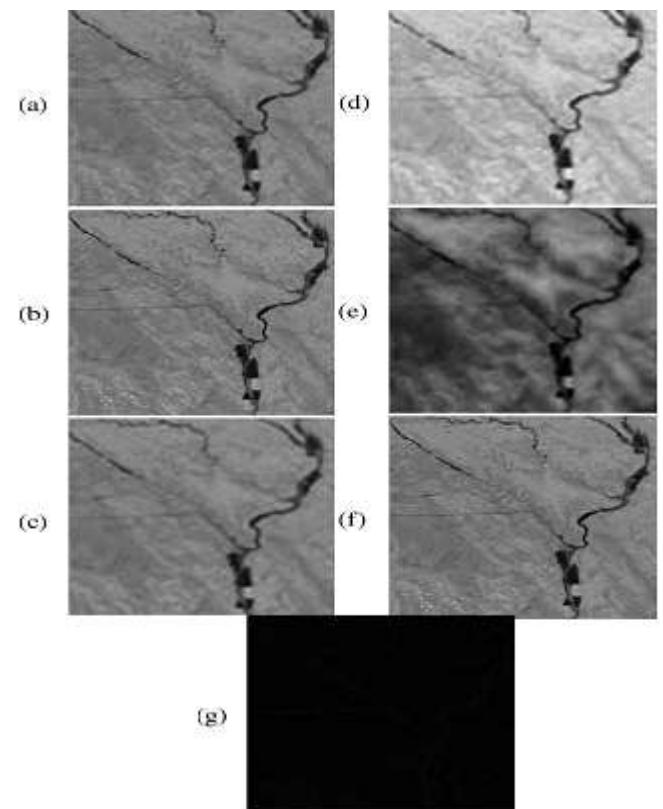


Figure 6: (a) Low-resolution image obtained from down sampling of the high-resolution satellite image through two cascaded DWT, (b) original high resolution satellite image, (c) bicubic interpolation-based resolution enhancement,(d) WZP, (e) WZP and CS technique, (f) the proposed image resolution enhancement technique, and (g) the difference between the original high resolution satellite image and the image enhanced by the proposed technique with enlargement from 128×128 to 512×512.

TABLE I
PSNR (DECIBELS) RESULTS FOR RESOLUTION ENHANCEMENT FROM 128×128 TO 512×512 ($\alpha=4$) FOR PROPOSED TECHNIQUE COMPARED WITH CONVENTIONAL AND STATE-OF-ART TECHNIQUES

Method / Image	PSNR(dB)			
	Fig 6-1	Fig 6-2	Fig 7-1	Fig 7-2
Bilinear	25.78	28.94	23.67	20.91
WZP (Db.9/7)	26.67	28.14	22.91	21.76
WZP and CS SR	28.78	30.13	23.89	23.56
Demirel and Anbarjafari	31.11	31.54	27.08	24.73
DWT	30.67	33.39	30.22	26.03
The Proposed Method (DWT with bicubic interpolation)	40.12	41.22	40.92	39.05

TABLE II
RMSE RESULTS FOR RESOLUTION ENHANCEMENT FROM 128×128 TO 512×512 ($\alpha=4$) FOR PROPOSED TECHNIQUE COMPARED WITH CONVENTIONAL AND STATE-OF-ART TECHNIQUES

Method / Image	RMSE			
	Fig 6-1	Fig 6-2	Fig 7-1	Fig 7-2
Bilinear	3.62	3.02	4.09	4.79
WZP (Db.9/7)	3.44	3.16	4.27	4.56
WZP and CS SR	3.05	2.82	4.04	4.11
Demirel and Anbarjafari	2.66	2.60	3.36	3.85
DWT	2.44	2.32	2.80	3.57
The Proposed Method (DWT with bicubic interpolation)	2.04	2.11	2.56	3.33

TABLE III
ENTROPY RESULTS FOR ENHANCEMENT FROM 128×128 TO 512×512 ($\alpha=4$) FOR PROPOSED TECHNIQUE COMPARED WITH PREVIOUSLY INTRODUCED RESOLUTION ENHANCEMENT TECHNIQUE, AS WELL AS LOW RESOLUTION AND HIGH RESOLUTION ORIGINAL IMAGES

Method / Image	Entropy			
	Fig : 6-1	Fig: 6-2	Fig: 7-1	Fig: 7-2
Low resolution satellite image (8 bit unsigned)	2.975	4.745	2.727	3.586
Low resolution satellite image(double precision)	5.8327	7.822	7.434	7.333
Original high resolution satellite image	5.968	7.872	7.578	7.484
The Proposed Method (DWT with bicubic interpolation)	5.937	7.758	7.424	7.190

The input image i.e. satellite image has a PSNR value 24.3898 and MSE value 236.14. This image is a colour image of 640×480 pixel. This image is converted into gray scale image. On application of DWT with an intermediate

state called interpolation, on this image, gives an enhanced image with a PSNR value 29.431 and MSE value 7.4122, clearly indicating the enhancement for the image.

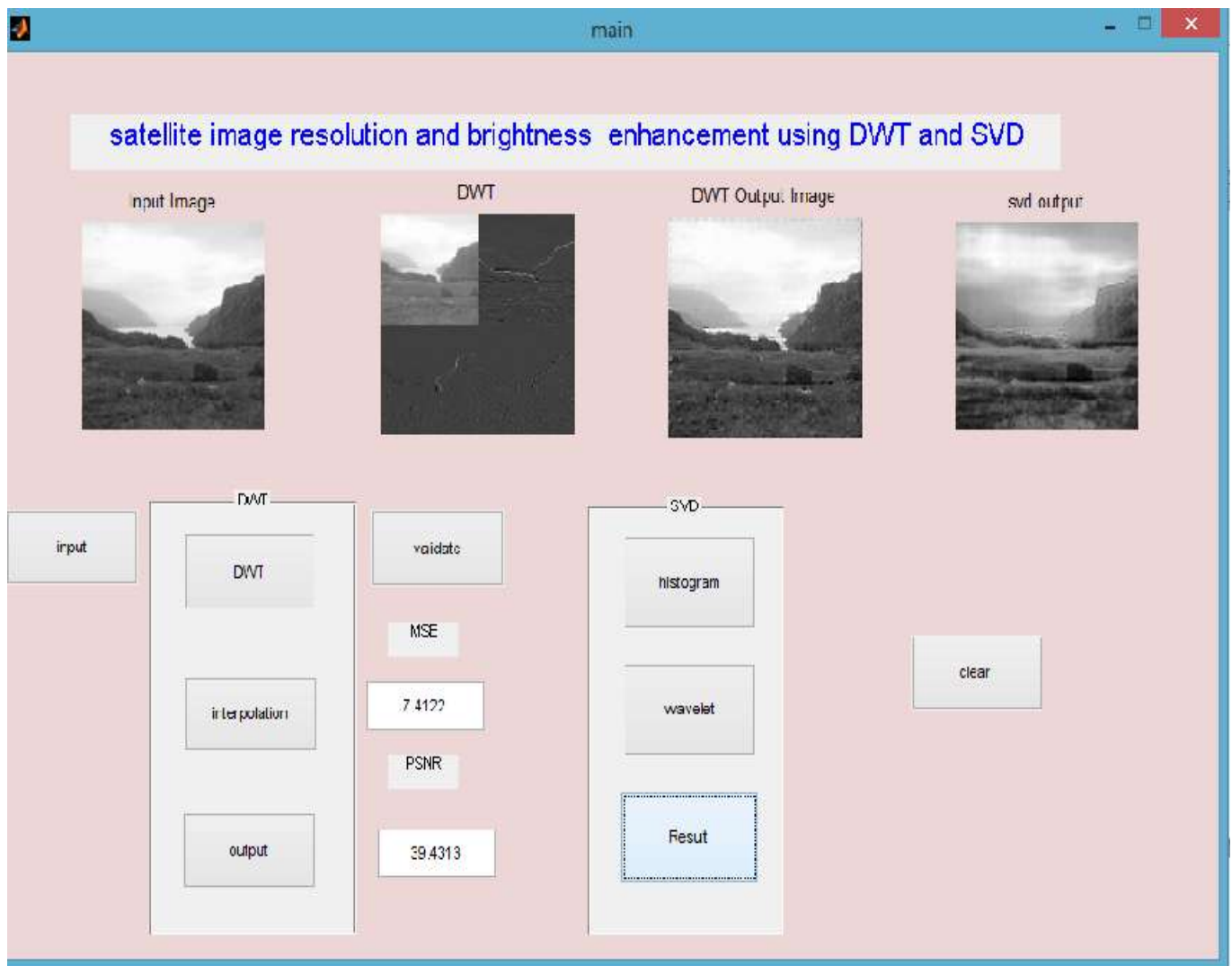


Figure 7: GUI Output from MATLAB

Hence by seeing the output and corresponding values we can confirm that resolution of the image has been enhanced twice that of the input image and by viewing the output we can estimate the enhancement in brightness of the image.

This work finds applications in many fields mainly where the satellite images are used. Satellite images have many applications in meteorology, agriculture, geology, forestry, landscape, biodiversity conservation, regional planning, education, intelligence and warfare. The enhancement in images as a result of this work leads to improvement in all the above fields.

V. CONCLUSIONS

This paper has proposed a new resolution enhancement technique based on interpolation of high-frequency sub band images obtained by DWT and input image. Also this paper has proposed a brightness enhancement technique

based on SVD transform of LL band image obtained from DWT process.

The proposed technique has been tested on well-known benchmark images, where their PSNR and RMSE and visual results show the superiority of the proposed technique over the conventional and state-of-art image resolution enhancement techniques.

The PSNR improvement of the proposed technique is up to 7.19 dB compared with the standard bilinear interpolation.

This work is mainly preferred for low resolution images though they give enhancement output to high resolution images as well. The precision and accuracy of enhancement will be more for low resolution images when compared with high resolution images. When this work is applied to high resolution images, we only get an accuracy of 70% but for low resolution images we obtain an accuracy of about 95% on the output image.

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