Lossless Compression of Satellite Images using a Versatile Hybrid Algorithm

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Abstract. The remote sensing images taken from various satellites have high resolution and occupy a lot of storage space. It, therefore, becomes difficult to send a greater number of images to the base station. Image compression becomes inevitable in such cases. Satellite image compression decreases repetition in representation of data so that the storage cost and transmission reduces and compensates for the limited on-board resources, in terms of large-scale memory and downlink bandwidth. The aim of this paper is to perform lossless image compression on satellite imagery using a hybrid (DWT-RLE) algorithm to obtain higher compression ratios. This compression is implemented using the software tool MATLAB.

1. Introduction

Remote sensing is the art of acquiring characteristics of an object or an area without being in physical contact with it. Satellites incorporate remote sensing using radio waves for transmission and reception of data. They have a plethora of applications, including imaging, communication, weather forecast, space exploration, military, etc. Some of the imaging satellites are SPOT, IKONOS, Cartosat, Worldview, and QuickBird. Transmission of large panchromatic, multispectral, and hyperspectral images increases the data volume making image compression inevitable. Image compression is broadly classified as lossy and lossless. In lossy image compression, we lose some information, but in lossless image compression, compression can be obtained without any loss of data. Image compression thus becomes an important step in any image processing application.

Wavelet transform has emerged as an essential tool of choice for image compression. The real-world data represents slowly changing trends or oscillations with abrupt transitions. Fourier transform represents data as a sum of sine waves that are continuous and not localized in time or space. It thus cannot represent abrupt changes giving rise to wavelets that accurately can measure abrupt changes. A wavelet is a localized wave with zero mean. The two main components are shifting and scaling. Depending on these two parameters, the wavelet can shrink or expand and shift over time. The compressed wavelet can capture abrupt changes, whereas a stretched wavelet captures slow changes in a signal. The oscillations in a wavelet depend on its vanishing moments.
FIR wavelet filter’s length depends on the support size. Different types of wavelets like Morlet, Haar, Mexican Hat, Daubechies, Gaussian, Symlets, Coiflets, Biorthogonal, etc., have different properties. Wavelets with fewer vanishing moments and have less coefficients can be used for compression where smooth reconstruction of an image can be obtained.

Run-Length Encoding (RLE) is a lossless compression methodology which is a relatively uncomplicated form of data compression. The data here is repeated in succession. Instead of representing all the elements, it is stored as a single data value and count. Let us consider a black and white image which has a greater number of white pixels than black. There will be many long runs of white pixels in the blank space and short runs of black pixels within the text.

```
WWW WWW WWW WWW WWB WWW WWW WWW WWW WWW WWW WWW WWW B WW
B W WWW WWW
```

After employing RLE to the above line, we get the below code: 9W B 11W 3B 20W 2B 13W.

The paper presents the survey on the various compression methods which provides good scalability and efficiency. [1-20]

The rest of the paper is categorized as follows. Literature Survey done is shown in Section 2. Section 3 explains the proposed Lossless Image Compression Algorithm. Experiment results are presented in Section 4. Concluding remarks are specified in Section 5.

## 2. Literature Survey

D. Gowri Sankar Reddy [21] developed a wavelet thresholding method to compress LANDSAT images. The image is first encoded with the Discrete wavelet transform using db4 wavelet. After decomposition into frequency bands, the LL coefficients are the approximate coefficients where most of the energy is concentrated, and much of the information is available. The other LH, HL, HH, which are the detail coefficients, have the less significant information. Image compression is achieved by truncating the detail coefficients. By varying threshold, the bit rate can be obtained. Using the proposed method, better PSNR (Peak Signal-to-noise ratio) was obtained for low bit-rate applications. This paper uses only one wavelet, and the thresholding holds good only for LANDSAT images. The proposed method cannot provide better PSNR for high bit-rate applications.

Multispectral images acquire data within the definite wavelength ranges across the band of the electromagnetic spectrum. It requires a lot of memory for storage. Dr. S. Prashantha [22] proposed a multispectral image compression algorithm using Daubechies wavelets, Symlet wavelets, Coiflet wavelet, and Bi-orthogonal wavelet. DWT is applied to the image taking a single band at a time. Depending on the application, decomposition level is selected. After applying the wavelet filters, the image undergoes thresholding where the compression takes place. Db1 and Biorthogonal wavelets obtain higher compression ratios compared to other wavelets. The algorithm proposed uses only multispectral images and neither panchromatic nor hyperspectral images. Though many wavelets are compared using DWT, it does not include any encoding technique to increase the compression ratio.

Sulaiman Khan [23] presented an approach of Haar wavelet transform, Discrete Cosine Transform, and Run-Length Encoding techniques for advanced manufacturing processes with higher image compression ratios. The images are segmented into 8X8 blocks and then decoded to construct the original image. An input image is given to the compression system, which converts the image to a bitstream. Later, a compression technique is applied. To achieve the decompressed resultant image, reconstruction of the original image is performed. The proposed algorithm works with a compression rate of 97.7%. The results showed that the DHT algorithm has a higher compression ratio and peak signal to noise ratio than other algorithms. It is found to be more efficient, less complex, cost-effective, and easy to implement. The main disadvantage of this paper is that it uses
only Haar wavelet, which gives less compression ratio. Using DCT, the image must undergo segmentation into 8X8 blocks before it undergoes compression making the process more complex.

3. Proposed Algorithm
The proposed hybrid algorithm, which combines Discrete Wavelet Transform (DWT) and Run-Length Encoding (RLE), overcomes the above disadvantages. Using DWT, the image can be used as a whole and need not be segmented as in Discrete Cosine Transform (DCT). This algorithm can compress both panchromatic and multispectral images of different resolutions, image formats, intensities, and wavelengths. The algorithm has been designed to use and compare five types of wavelets: Haar, Daubechies, Symlets, Coiflets, and Biorthogonal. It also can analyze various levels of decomposition. Apart from DWT, it uses a simple encoding technique, RLE, to enhance the compression ratio. When the wavelet coefficients are segregated using a given threshold value, the coefficients below the value are truncated to zero. Run-Length Encoding becomes an efficient coding technique when there is a lot of repetitive data.

The data set in this proposed method are remote sensing images taken from the satellites CARTOSAT2, CARTOSAT3, INSAT3DR, CHANDRAYAAN2, and MARSORBITER. This consists of ten images, out of which five are panchromatic (Figure 1), and five are multispectral (Figure 2). The images are shown below.

![Panchromatic images](image1.png)
Figure 2. Multispectral images

The proposed algorithm for lossless image compression (Figure 3) consists of the following steps.

1. The satellite image is taken as the input.
2. Discrete Wavelet Transform (DWT) is applied to the image.
3. The resultant coefficients are segregated depending on the threshold value.
4. The coefficients are then quantified.
5. Run-Length Encoding is applied to the quantified coefficients to obtain the compressed output bitstream.

Figure 3. Block diagram of DWT-RLE

The satellite image is taken as the input. If it is a panchromatic image, it is directly wavelet decomposed. But, if the image is multispectral, it is converted to grayscale, and then wavelet decomposed. In the wavelet transform, a choice of five wavelets (Haar, Daubechies, Symlets, Coiflets, and Biorthogonal) are given. After selecting the type of wavelet, an option of decomposition level is shown. If 1 is given, Level 1 decomposition is performed on that image (Figure 4). We get four sub-bands where LL has the approximate coefficients and HL, LH and HH have the detail coefficients. Most of the information is stored in the approximate coefficients, and detail coefficients have less information. The LL band can be further divided depending on the decomposition level.
The flow of the proposed hybrid algorithm is implemented as follows. The panchromatic image of Doha taken by the satellite CARTOSAT2 is taken as the input. (Figure 5).

**Figure 4.** Wavelet Decomposition levels

**Figure 5.** Input image
To implement DWT, an option is provided to choose a wavelet from the five wavelets: Haar, Daubechies, Symlets, Coiflets, and Biorthogonal in the Command Window of MATLAB. Here we have given option 2 and chosen Daubechies wavelet. Next, the decomposition level must be entered. It is entered as Level 1. The flow of inputs can be viewed in the following Figure 6.

![Figure 6. Inputs for wavelet, decomposition level, and threshold in MATLAB tool](image)

After performing Level 1 decomposition, we get the following image (Figure 7).

![Figure 7. Level 1 decomposition image](image)
The coefficients are then subjected to an input threshold value (given as 50), where the coefficients below the threshold value are truncated. The following equation gives the equation for thresholding.

\[
\text{if } \text{abs}(C[i]) < \text{TH}, \text{then } C[i] = 0
\]  

where \(C[i]\) = wavelet decomposed vector  
\(\text{TH}\) = Threshold value

The resultant coefficients are Run-Length Encoded, where the data repeated in succession is stored as a single data value with its count. As there is no loss of information, the output bitstream is thus compressed in a lossless way. With the help of the compressed output bitstream, the Compression ratio is calculated by the given formula.

\[
\text{Compression ratio} = \frac{\text{Original Image Size}}{\text{Compressed Image Size}}
\]

A compression ratio of 8.2338 is obtained for Level 1 Decomposition of Daubechies Wavelet. The compression ratio increases when the level of decomposition increases.

4. Results and Discussion

This paper aims to achieve and analyze high compression ratios using different wavelets and Encoding using the Run-Length Encoding technique. The ten satellite images, both panchromatic and multispectral, are wavelet decomposed using the five wavelets: Haar, Daubechies, Symlets, Coiflets, and Biorthogonal. The compression ratios are analyzed with the three decomposition levels: Level 1, Level 2, and Level 3. The threshold value is taken constant throughout all the comparisons. For example, we take a sample image of a crater on the moon taken by Chandrayaan2. As it is panchromatic, it is directly subjected to Wavelet Decomposition. Firstly, the wavelet is chosen from the given five wavelets and then input the decomposition level. The coefficients are Run-Length Encoded to obtain the compressed output bit stream depending on the given threshold value. The compression ratio is lastly calculated.

If we choose the Daubechies wavelet, Level 1 decomposition, threshold value as 50, the compression ratio is calculated as 18.97. If the Level 2 decomposition is selected with the same wavelet and threshold value, the compression ratio obtained is 41.19. If Level 3 is chosen, the compression ratio would be 48.87 (Table 1). The following table constitutes the comparison of compression ratios of the ten satellite images using five wavelets and three decomposition levels.

Table 1. Comparison of Compression ratios of different images with various wavelets

| Images | Haar | Daubechies | Symlets | Coiflets | Biorthogonal |
|--------|------|------------|---------|----------|--------------|
|        | 1    | 2          | 3        | 1        | 2            |
| doho2_cartosat2.jpg | 7.47 | 10.58 | 11.20 | 8.23 | 12.37 | 11.20 | 8.15 | 12.22 | 33.01 | 7.96 | 11.76 | 12.52 | 8.60 | 11.23 | 11.36 |
| earth_2_10356.jpg | 9.29 | 12.46 | 13.31 | 10.32 | 14.56 | 15.51 | 10.37 | 14.48 | 35.50 | 10.15 | 14.38 | 15.15 | 10.13 | 12.37 | 12.37 |
| moon_chandrayaan.jpg | 11.09 | 15.44 | 15.90 | 12.09 | 17.59 | 17.83 | 11.98 | 17.49 | 37.76 | 11.68 | 16.85 | 17.21 | 12.84 | 14.32 | 13.89 |
| moon_chandrayaan2_01.jpg | 18.61 | 38.46 | 46.24 | 18.97 | 41.19 | 46.87 | 18.94 | 40.61 | 46.64 | 18.53 | 40.41 | 46.86 | 19.03 | 33.41 | 31.48 |
| doho_alport_cartosat3.jpg | 10.07 | 31.53 | 35.54 | 10.18 | 31.53 | 67.67 | 10.17 | 31.53 | 66.79 | 10.14 | 31.20 | 66.37 | 10.12 | 20.59 | 21.53 |
| alexandria_cartosat2.jpg | 7.12 | 12.11 | 13.53 | 8.85 | 15.26 | 17.07 | 8.69 | 14.79 | 16.56 | 8.40 | 14.07 | 15.68 | 9.20 | 13.02 | 13.18 |
| kishanghat_cartosat2.jpg | 9.86 | 13.98 | 14.34 | 11.02 | 16.85 | 17.41 | 10.89 | 16.48 | 17.04 | 10.74 | 15.03 | 16.54 | 11.79 | 14.83 | 14.72 |
| mar_molden.jpg | 18.37 | 67.32 | 75.12 | 18.24 | 68.35 | 78.82 | 18.22 | 68.26 | 100.4 | 18.21 | 68.05 | 158.6 | 18.22 | 58.59 | 60.41 |
| vanthillips_cartosat3.jpg | 10.32 | 23.56 | 28.50 | 10.42 | 29.72 | 38.58 | 10.42 | 29.29 | 37.89 | 10.39 | 28.04 | 35.87 | 10.42 | 28.96 | 37.85 |
| swedenagar_cartosat2.jpg | 10.14 | 39.45 | 59.38 | 10.08 | 39.69 | 112.0 | 10.13 | 40.06 | 128.2 | 10.10 | 40.24 | 121.9 | 10.12 | 40.52 | 112.9 |

The above table is plotted into graphs for all the ten images, panchromatic and multispectral, to analyze and compare the various compression ratios obtained for different wavelets and decomposition levels. The five wavelets and the decomposition levels are shown on the X-axis and the Compression Ratio on the Y-axis in Figure 8.
Figure 8. A plot of comparison of compression ratios
5. Conclusion

The ten satellite panchromatic and multispectral images are subject to compression using the hybrid Discrete Wavelet Transform (DWT) and Run-Length Encoding (RLE) algorithm. The images are analyzed using the five wavelets: Haar, Daubechies, Symlets, Coiflets, and Biorthogonal. Levels 1, 2, and 3 decompositions are performed on the images while keeping the threshold value constant. It can be observed that higher compression ratios are achieved using Daubechies and Biorthogonal Wavelets than other wavelets. Run-Length Encoding enhances the compression by replacing the repetitive long runs of truncated data with only a single value and a count.

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