Pertanika J. Sci. & Technol. 25 (S): 205 - 214 (2017)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

# Zero-Padding in DWT Satellite Image Compression

**Suhaidi Shafie[1,2]*, Halah Saadoon Shihab[1], Fauzan Ahmad[3] and A. R. Ramli[2]**

[1]*Institute of Advanced Technology, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia*
[2]*Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia*
[3]*Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, 54100 Kuala Lumpur, Malaysia*

## ABSTRACT

Discrete Wavelet Transform (DWT)-based image compression techniques have been utilized in most of the earth observation (EO) satellites launched during the last few decades, since they have proved to be more efficient than other methods used previously with remote sensing multispectral imaging payloads. The efficiency of these techniques is mainly due to their high compression ratio that can be achieved while maintaining the quality of the compressed image. Also, they are considered multi-resolution compression techniques. However, these techniques are considered computationally demanding, due to their complex and sophisticated hardware. Due to the limited computational resources available on-board small satellites, they are considered one of the important criteria when choosing the satellite image compression method, along with the compression ratio and quality of the reconstructed image. Hence, an alternative DWT-based method was proposed, developed and implemented in this work with the aim of reducing the computational resources on-board a small satellite, replacing the regular DWT thresholding and quantization processes that are usually used to achieve lossy compression, with the zero-padding technique. This method will also help to control the change in the compression ratio and quality of the reconstructed image according to the end-user's scientific needs of the satellite image. The results of this work indicated, objectively and subjectively, that a decrease in the computational resources required on-board satellites was achieved by decreasing the processing time needed to complete the compression, without a significant difference in quality of the image reconstructed at the ground station.

*Keywords:* Satellite images, Remote sensing, Image compression, Discrete Wavelet Transform

ARTICLE INFO

*Article history:*
Received: 24 August 2016
Accepted: 03 Jun 2017

*E-mail addresses:*
suhaidi@upm.edu.my (Suhaidi Shafie),
hala_alubaidi@yahoo.com (Halah Saadoon Shihab),
fauzan.kl@utm.my (Fauzan Ahmad),
arr@upm.edu.my (A. R. Ramli)
*Corresponding Author

ISSN: 0128-7680 

## INTRODUCTION

Optical remote sensing imagers mounted on-board satellites employ multispectral sensors, such as visible, near infrared and shortwave infrared sensors, to form images of the earth's surface by detecting solar radiation reflected from objects on the ground (Dumitru et al., 2015), converting the reflected surface information into an image format (Mulla et al. 2015). Hence, multispectral images are used in remote sensing to a large degree, and they are beginning to be used in several other applications as well, such as medical imagery and quality control (Delcourt et al., 2010).

Since on-board computational resources are limited (Thiebaut & Camarero, 2011), image compression is used in many space missions to reduce on-board data storage and transmission bandwidth requirements from the satellite to the ground station (Yu et al., 2009).

Image compression schemes are divided into two main categories: Lossless and Lossy (CCSDS Secretariat Space Communications and Navigation Office 2011). Lossless image compression allows an image to be compressed and decompressed without any information loss. In lossy compression schemes, a certain amount of loss of data is accepted. Although it is impossible to reconstruct the exact original image using lossy image compression, it provides a much higher compression ratio than lossless compression (Faria et al., 2012), hence, it is used in this work.

Raw multispectral images captured by remote sensing satellites have very high *resolutions* (Raju et al., 2016). Hence, satellite images cannot be dealt with in the same manner as low resolution images, especially when taking into consideration the limited resources on-board satellites (Yu et al., 2009). Hence, choosing the suitable compression technique for such images should be carefully considered in order to achieve high compression ratios (CR) to decrease the bandwidth required to transmit data from satellite to earth while maintaining as much as possible the important scientific information in the image when reconstructed on earth.

Discrete Wavelet Transform (DWT)-based compression methods, such as JPEG2000 (Taubman 2002), have been widely used more than other transform-based methods, such as the DCT (Yu et al. 2009) since DWT is considered a multi resolution transform (Singh & Tripathi, 2014), and also due to the high compression ratio that can be achieved using these techniques (Thiebaut & Camarero, 2011) while maintaining a good level of quality of the reconstructed images. However, this method will cause an increase in the computational resources when used on-board satellites, due to its complexity. The zero-padding of DWT detail coefficients was used instead of thresholding and quantization process in this work since:

1. This method can decrease the computational resources on-board satellites.
2. It was not discussed in detail in previous works, especially with respect to satellite images.

## DWT-BASED LOSSY IMAGE COMPRESSION

### Basic Architecture of a DWT-based Lossy Image Compression System

The DWT-based lossy image compression systems are usually accomplished using three forward main steps and three inverse steps as shown in Figure 1.

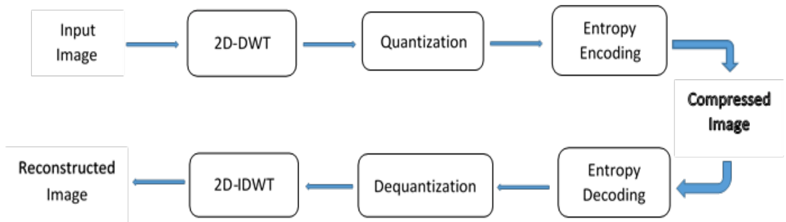


*Figure 1.* A basic DWT-based lossy image compression system

The first stage is the forward transform (transformation from spatial domain to frequency domain), represented in the current work by 2 Dimensional-DWT, acquiring separated high and low frequency coefficients in order to concentrate the most important information into as few low frequency components as possible.

The second stage is represented by thresholding and quantization. *Thresholding* can be identified by setting all 2D-DWT coefficients that are less than a specific value to zero, in order to eliminate the less important information from the DWT coefficients to increase the compression ratio, thus, the higher the threshold value, the more CR but lower quality will be obtained. *Quantization* is an irreversible process, represented by rounding the resulting coefficients after thresholding.

The third forward stage is usually represented by the entropy encoding lossless process, adjusting the coded information to get further bit rate reduction in order to increase the compression ratio.

The DWT-based image compression can be classified into several methods according to the entropy coding technique used, such as JPEG2000 (Rabbani & Joshi 2002), Embedded Zero tree Wavelet algorithm (EZW) (Shapiro, 1993), Set Partitioning In Hierarchical Trees (SPIHT) (Said et al., 1996), and the CCSDS-IDC (Image Data Compression) (Faria et al., 2012). The coding for all these DWT-based methods depends on separating the significant from the insignificant values.

The entropy coding will not be considered in this paper since it will have an impact on the compression ratio (CR) results according to the type of the encoder used.

The forward compression stages take place on-board the satellite whereby the compressed satellite image is transmitted through a radio frequency (RF) link to a ground station, where the inverse stages take place to reconstruct the image.

Each level of the 2D- DWT transform produces two types of coefficients according to the filters used, based on the fact that the human visual system can recognize low frequency information much more efficiently than the high frequency information. These coefficients are:

- The *approximation coefficients* (cA): they indicate the most important information of the image, resulting only from low pass filters.
- The *detail coefficients*: they indicate the high frequency, less important information of the image, identified by the horizontal (cH), vertical (cV) and diagonal (cD) coefficients.

These coefficients are represented for 2-levels of 2D-DWT as shown in Figure 2 (Anon n.d.), where the symbols L and H indicate the Low and High pass filters used in this process respectively. Hence, the LL in each level represents the Approximation coefficients, while the other HL, LH and HH indicate the Horizontal, Vertical and Diagonal detail coefficients respectively.

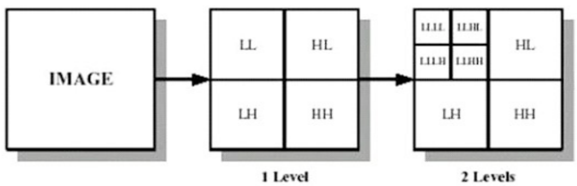


*Figure 2.* DWT- image compression levels

## Image Compression Metrics

The image compression performance can be evaluated based on several factors. These factors will be presented in the current work:

- Objectively (using CR and PSNR, as defined below)
- Subjectively (visually)

Compression Ratio (CR): indicates the compression achieved for an image. It can be computed using equation (1).

$$CR = Size\ of\ Original\ ImageSize\ of\ Compressed\ image \quad (1)$$

*Peak Signal to Noise Ratio (PSNR)*: gives the numerical value for the quality of an image after being compressed and decompressed. It can be computed using equation (2). Units are in (dB).

$$PSNR=10\ log_{10}\frac{I^2}{MSE} \quad (2)$$

*Where I*: The allowable image pixel intensity level

Ex: for (8bpp) image, I= $(2^8\text{-}1)$ = 255

*Mean Square Error (MSE)*: Indicates level of distortion by comparing original data with the reconstructed data. It can be computed using equation (3).

$$MSE = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(A_{i,j} - B_{i,j})^2 \quad (3)$$

*Where:* *A*: Original image of size *M*x*N*
*B*: Reconstructed image of size *M*x*N*

## THE PROPOSED DWT SATELLITE IMAGE COMPRESSION:

The thresholding and quantization processes in the DWT-based compression technique were replaced in this work by a process which can be identified by padding one, two or all the three of the 2D-DWT detail coefficients with zeros, resulting in 8 zero-padding cases. This technique will help to decrease the computational resources on-board satellites and also change the CR and PSNR values of the satellite image as required by changing the zero-padding cases.

The proposed technique should decrease the computational resources on-board satellites for several reasons:

1. Rounding is not used, as no thresholding or quantisation is needed.
2. The task of the DWT encoder that should be used after this process to accomplish the separation of the significant from the insignificant coefficients will be much simpler, since the coefficients were already separated using this technique.

This will result in a decrease in image compression time and cost due to the decrease of compression hardware requirements used on-board the satellite.

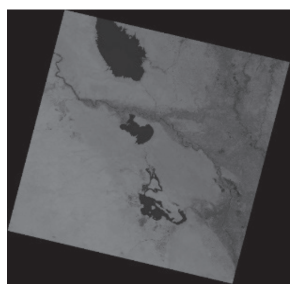

*Figure 3.* Baghdad (B6)

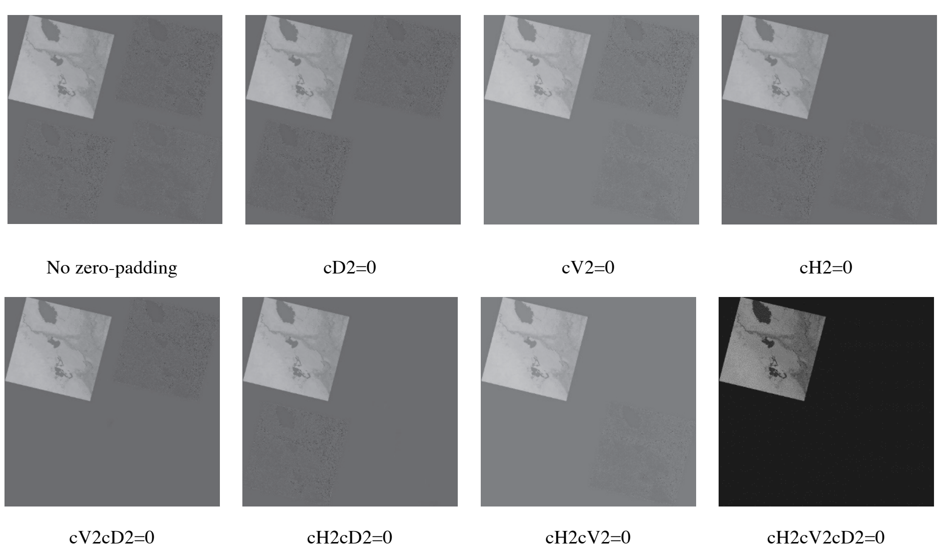


*Figure 4.* 2nd level of 2D-DWT image compression using Zero-Padding technique cases (compressed images)

Figure 4 illustrates the 8 zero padding cases of the 2nd level of 2D-DWTcompression applied to the Baghdad B6 satellite image shown in Figure 3,captured by the LANDSAT 8 earth observation satellite, having a resolution of (7924×7924) pixels and a bit depth of 16 bpp, to simulate an on-board satellite image compression process.

## RESULTS AND DISCUSSION

### Results of the Proposed DWT Technique

Figure 5 shows the results of the second level of 2D-DWT (represented by CR and PSNR), according to the change in the zero-padding cases, after being applied to the Baghdad (B6) satellite image (Figure 3), employing the bior 3.7 wavelet. The results were generated using MATLAB software.

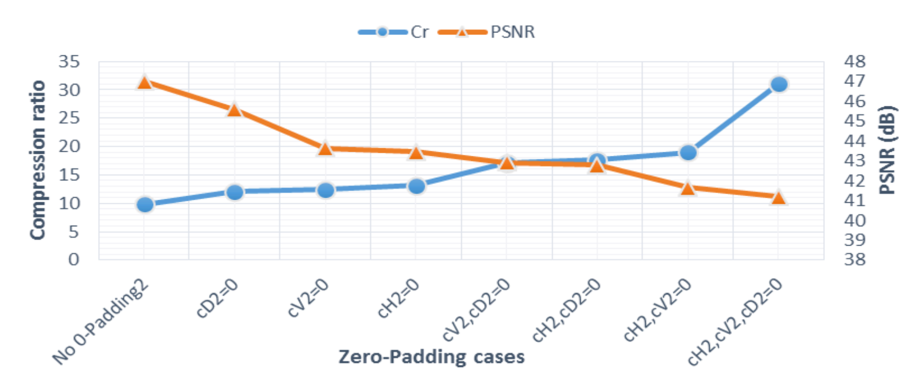


*Figure 5.* Objective results for 2nd level of 2D-DWT image compression

It can be noticed from the results that when the zero-padding technique is used, the CR and PSNR values change according to the *type* and *number* of the 2D-DWT detail coefficients to be reconstructed.

**Types of detail coefficients.** Different types of detail matrices in each image contain different amounts of data according to the image type and the filter used. In the Baghdad satellite image, for example, the Horizontal coefficient matrix (cH) is the highest in information followed by the vertical (cV) while the diagonal (cD) includes the least information. However, that is not the case for all types of images, which may differ in that order.

**Number of Detail Coefficient Matrices**.The more matrices of 2D-DWT detail coefficients are zero padded in each level, the higher compression ratios and less but satisfactory PSNR values can be achieved, since less detail coefficients will be reconstructed.

### The Time Gain Resulting From using the Proposed DWT Method

Figure 6 demonstrates the processing time during two-levels of 2D-DWT satellite image compression when using the DWT-standard quantization or the zero-padding technique for different values of PSNR.

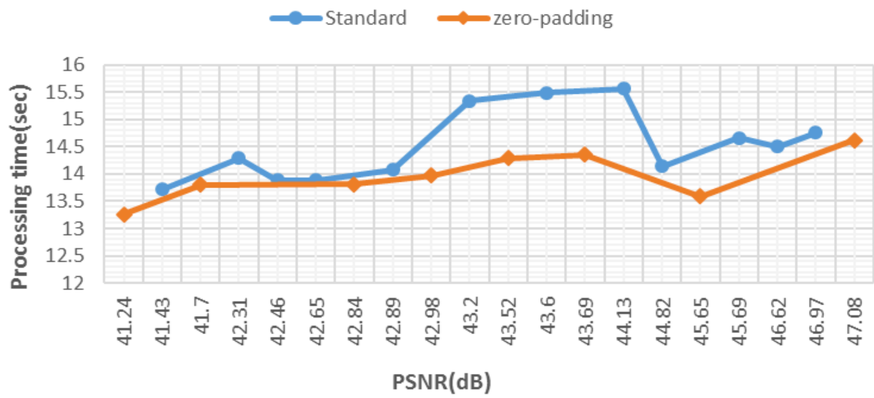


*Figure 6.* Processing time for image compression when using the DWT-standard quantization & the zero-padding technique

It can be noticed from Figure 6 that a time gain was achieved using the Zero-Padding technique. This was accomplished without a significant difference in the reconstructed image quality (PSNR), as shown objectively in Figure7, for different values of compression ratio, and subjectively in Figure 8.

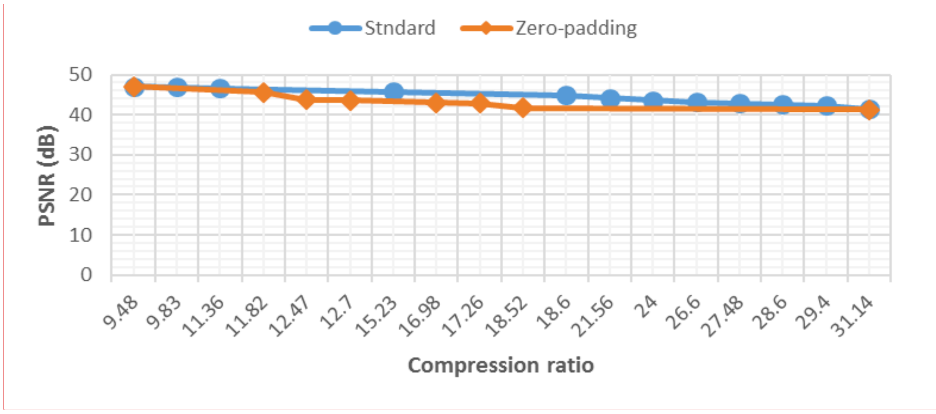


*Figure 7.* Quality of the reconstructed image when using the DWT-standard quantization & the zero-padding method

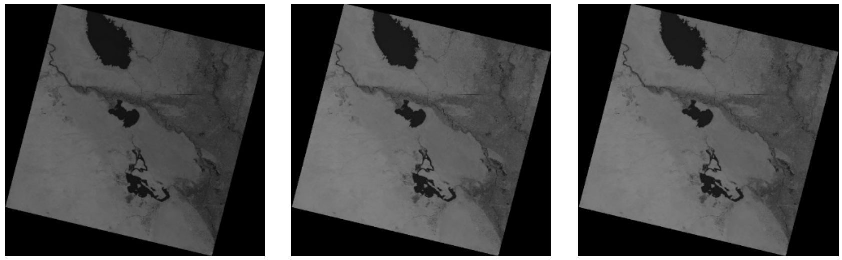


*Figure 8.* The visual representation of the reconstructed image quality difference between the DWT-standard quantization & the zero-padding method when CR=26

## CONCLUSION

In conclusion, it is feasible to employ the zero- padding technique in the DWT- based image compression on-board satellites instead of the regular thresholding and quantization processes, since 1) it will help decrease the computational resources required for image compression on-board satellites, without losing the good quality of the satellite image after being reconstructed at the ground station, and 2) a good level of control to change the CR and PSNR values for each DWT-level can be achieved while guaranteeing that all the important information in the approximation coefficients will not be involved in the zero-padding process. This is easier than choosing a threshold value for all coefficients, which can be tricky, since some of the important information might be lost.

## REFERENCES

Anon, Silicon Mentor. Available at: http://www.siliconmentor.com/image-compression-using-dwt/.

CCSDS Secretariat Space Communications and Navigation Office, 7L70 Space Operations Mission Directorate NASA Headquarters, 2011. *IMAGE DATA COMPRESSION (Recommendation for Space Data System Standards),* Washington, DC 20546-0001, USA.

Delcourt, J., Mansouri, A., Sliwa, T., & Voisin, Y. (2010, June). An adaptive multiresolution-based multispectral image compression method. In *International Conference on Image and Signal Processing* (pp. 54-62). Springer Berlin Heidelberg.

Dumitru, C. O., Cui, S., & Datcu, M. (2015, March). A study of multi-sensor satellite image indexing. In *2015 Joint Urban Remote Sensing Event (JURSE)* (pp. 1-4). IEEE.

Faria, L. N., Fonseca, L. M., & Costa, M. H. (2012). Performance evaluation of data compression systems applied to satellite imagery. *Journal of Electrical and Computer Engineering, 2012*(18), 1-5.

Mulla, A., Baviskar, J., Naik, R., & Baviskar, A. (2015, March). Enhanced quality LANDSAT image processing based on 4-level Sub-Band Replacement DWT. In *2015 IEEE Aerospace Conference* (pp. 1-7). IEEE.

Rabbani, M., & Joshi, R. (2002). An overview of the JPEG 2000 still image compression standard. Signal processing: *Image communication, 17*(1), 3-48.

Raju, V. B., Sankar, K. J., Naidu, C. D., & Bachu, S. (2016). Multispectral Image Compression for various band images with High Resolution Improved DWT SPIHT. *International Journal of Signal Processing, Image Processing and Pattern Recognition, 9*(2), 271-286.

Said, A., & Pearlman, W. A. (1996). A new, fast, and efficient image codec based on set partitioning in hierarchical trees. *IEEE Transactions on Circuits and Systems for Video Technology, 6*(3), 243-250.

Shapiro, J. M. (1993). Embedded image coding using zerotrees of wavelet coefficients. *IEEE Transactions on signal processing, 41*(12), 3445-3462.

Singh, A. K., & Tripathi, G. S. (2014). A comparative study of dct, dwt & hybrid (dct-dwt) transform. *Global Journal of Engineering Science and Researches(GJESR), 1*(4), 16–21.

Taubman, D. S., Marcellin, M. W., & Rabbani, M. (2002). JPEG2000: Image compression fundamentals, standards and practice. *Journal of Electronic Imaging, 11*(2), 286-287.

Thiebaut, C., & Camarero, R. (2011). CNES Studies for On-Board Compression of High-Resolution Satellite Images. In B. Huang (Ed.), *Satellite Data Compression*. New York, NY: Springer New York.

Yu, G., Vladimirova, T., & Sweeting, M. N. (2009). Image compression systems on board satellites. *Acta Astronautica, 64*(9), 988-1005.