UNIVERSITI PUTRA MALAYSIA

HIGH RESOLUTION SATELLITE IMAGE COMPRESSION USING ZERO PADDING DISCRETE WAVELET TRANSFORM AND DISCRETE COSINE TRANSFORM ALGORITHMS

HALAH SAADOON SHIHAB AL-OBAIDI

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By

HALAH SAADOON SHIHAB AL-OBAIDI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

December 2016

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DEDICATION

This work is dedicated

To

My dear Husband Sermed for your support

My two Boys Ahmed and Aws for all the inconvenience you went through, with patience, during this study

The memory of my dear Father, for your inspiration

My dear Mother, Brother, and Family, for all your warm feelings

My Dear Friends for all your moral support

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

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HALAH SAADOON SHIHAB AL-OBAIDI

December 2016

Chairman : Associate Professor Suhaidi b. Shafie, PhD
Faculty : Institute of Advanced Technology

Raw satellite images are considered high in resolution, especially multispectral images captured by remote sensing satellites. Hence, choosing the suitable compression technique for such images should be carefully considered, to achieve high values of compression ratio (CR) to decrease the data storage on-board satellites, and the bandwidth required to transmit data from the satellite to earth, while simultaneously maintaining the important scientific information of the image when reconstructed at the ground station. The Discrete Cosine Transform (DCT) and the Discrete Wavelet Transform (DWT)-based compression techniques have been utilized in most of the space missions launched throughout the last few decades due to their efficiency. However, both techniques have some drawbacks that should be addressed, such as blocking artefacts for DCT and computational complexity for DWT.

Several different hybrid compression methods based on DCT and DWT were used in previous works to utilize the positive properties and decrease the effect of the negative properties of these transforms. However, none of these hybrid methods were implemented on high resolution satellite images, and each method had one or more shortcomings. Hence, a proposed hybrid (DWT-DCT) method was presented and implemented in the current work on several satellite images, simulating an image compression system on-board a small satellite. This method can achieve higher values of compression ratio, through adding the 2D-DCT to the 2D-DWT second level coefficients instead of further complex levels of 2D-DWT compression. Besides, this method can maintain an acceptable reconstructed image quality through replacing the standard DWT thresholding and quantization processes with an alternative process that employed the zero-padding technique in a way that controlled the change in Compression Ratio (CR) and Peak Signal to Noise Ratio (PSNR), and helped to decrease the DWT processing time.

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Image compression was performed on several satellite images using DCT, DWT, and the proposed Hybrid method with the aim of comparing the results. Hence, it was indicated that the proposed hybrid (DWT-DCT) technique achieved better performance than the standalone DCT or DWT techniques. All the results were obtained objectively (by calculating the CR and PSNR values for each case using the MATLAB software package), and subjectively (Visually). A gain of 43.6%, 57.8% and 96.5% of CR was achieved using the proposed method relative to the DWT, for the satellite images Baghdad, Basra and Erbil respectively, with a negligible reduction in the reconstructed image quality. Hence, it was concluded that using the proposed method improved the satellite image compression, and it is feasible to be used on-board satellites.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

PEMAMPATAN IMEJ SATELIT BERESOLUSI TINGGI MENGGUNAKAN ALGORITMA TRANSFORMASI WAVELET DISKRET DAN TRANSFORMASI KOSINUS DISKRET DENGAN PELAPIK SIFAR

Oleh

HALAH SAADOON SHIHAB AL-OBAIDI

Disember 2016

Pengerusi : Profesor Madya Suhaidi b. Shafie, PhD
Fakulti : Institut Teknologi Maju

Imej satelit mentah dianggap tinggi dalam resolusi, terutamanya imej pelbagaispectral yang ditangkap oleh satelit penderiaan jauh. Oleh itu, memilih teknik mampatan yang sesuai untuk imej tersebut harus dipertimbangkan dengan teliti bagi mencapai nilai nisbah mampatan (CR) yang tinggi supaya dapat mengurangkan penyimpanan data pada satelit, dan lebar jalur yang diperlukan untuk menghantar data dari satelit ke bumi, serta pada masa yang sama dapat mengekalkan maklumat saintifik yang penting apabila imej dibina semula di stesen bumi. Teknik mampatan berasaskan Transformasi Kosinus Diskret (DCT) dan Transformasi Wavelet Diskret (DWT) telah digunakand alam kebanyakan misi angkasa yang dilancarkan sepanjang beberapa dekad yang lalu kerana kecekapan teknik tersebut. Walaubagaimanapun, kedua-dua teknik tersebut mempunyai beberapa kelemahan yang perlu ditangani, seperti artifak tersekat untuk DCT dan kerumitan pengiraan untuk DWT.

Beberapa kaedah pemampatan hibrid berbeza yang berasaskan DCT dan DWT telah digunakan dalam kerja-kerja sebelum ini untuk menggunakan ciri-ciri positif dan mengurangkan kesan daripada ciri-ciri negatif daripada kaedah penjelmaan ini. Walaubagaimanapun, tiada kaedah hibrid yang dilaksanakan pada imej- imej satelit beresolusi tinggi, dan setiap kaedah mempunyai satu atau lebih kekurangan. Oleh itu, kaedah yang dicadangkan iaitu hibrid (DWT-DCT) telah dibentangkankan dan dilaksanakan dalam kerja-kerja semasa untuk beberapa imej satelit, serta simulasi sistem pemampatan imej bagi sebuah satelit kecil. Kaedah ini boleh mencapai nilai-nilai nisbah mampatan yang lebih tinggi, melalui cara menambah 2D-DCT kepada pekali tahap kedua 2D-DWT dan bukannya tahap kompleks bagi mampatan 2D-DWT. Selain itu, kaedah ini juga boleh mengekalkan kualiti imej binaan semula melalui penggantian proses standard pengambangan dan pengkuantuman DWT dengan proses alternatif yang menggunakan teknik pelapik sifar dengan cara mengawal perubahan dalam ratio mampatan (CR) dan puncak isyarat kepada nisbah hingar(PSNR), dan ini membantu untuk mengurangkan masa pemprosesan DWT.

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Pemampatan imej telah dilakukan keatas beberapa imej satelit menggunakan DCT, DWT, dan kaedah Hibrid yang dicadangkan dengan tujuan untuk perbandingkan. Oleh itu, keputusan menunjukkan bahawa teknikyang dicadangkan iaitu hibrid (DWT-DCT) mencapa iprestasi yang lebih baik daripada teknik DCT atau DWT secara sendirian. Semua keputusan telah dijalankan secara objektif (dengan mengira nilai CR dan PSNR bagi setiap kes dengan menggunakan pakej perisian MATLAB), dan subjektif (visual). A keuntungan sebanyak 43.6%, 57.8% dan 96.5% daripada CR dicapai menggunakan cadangan kaedah relatif kepada DWT, untuk imej satelit Baghdad, Basra dan Erbil masing-masing, dengan pengurangan kecil dalam kualiti imej yang. Oleh itu, kesimpulannya kaedah yang dicadangkan dapat meningkatkan pemampatan imejsatelit dan berdaya maju untuk digunakan pada satelit.

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Finally, I must extend my deepest thanks and gratitude to my Husband, Sermed, and my two boys, Ahmed and Aws, for all the hardships that they went through patiently during my study, for having a busy wife and mother.

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I certify that a Thesis Examination Committee has met on 30 December 2016 to conduct the final examination of Halah Saadoon Shihab Al-Obaidi on her thesis entitled "High Resolution Satellite Image Compression using Zero Padding Discrete Wavelet Transform and Discrete Cosine Transform Algorithms" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

CR	Compression Ratio
PSNR	Peak Signal to Noise Ratio
MSE	Mean Square Error
DCT	Discrete Cosine Transform
2D-DCT	Two Dimensional Discrete Cosine Transform
DWT	Discrete Wavelet Transform
2D-DWT	Two Dimensional Discrete Wavelet Transform
B6	Band 6
NIR	Near Infrared
TIRS	Thermal Mapping and Estimated Soil Moisture
SWIR	Short Wave Infrared
JPEG	Joint Photographic Experts Group
RF	Radio Frequency
RGB	Red Green Blue
EO	Earth Observation
DPCM	Differential Pulse Code Modulation
CCSDS-LDC	Consultative Committee for Space Data Systems-Lossless Data Compression
KLT	Karhunen-Loeve Transform
DFT	Discrete Fourier Transform
WHT	Walsh-Hadamard Transform
NASA	National Aeronautics and Space Administration
CNES	Centre National d'Etudes Spatiales
EZW	Embedded Zero Tree Wavelet algorithm

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SPIHT	Set Partitioning in Hierarchical Trees
ECG	Electrocardiogram signals
ZPSVD	Zero Padding Singular Values Decomposition
USGS	United States Geological Survey

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CHAPTER 1

INTRODUCTION

1.1 Satellite Images

Image sensors mounted on board satellites record the amounts of reflected energy from objects on the ground, remotely. This information is stored and transformed to an image format. Hence, this process is called *Remote Sensing*.

Optical remote sensing utilizes sensors that capture imaging data in multiple spectral bands, such as visible, near infrared and shortwave infrared, to create a data set for each image of the earth's surface. Hence, multispectral images are used in remote sensing to a large degree, and they are starting to be used in several other applications such as medical imagery and quality control, among others.

Raw multispectral images captured by remote sensing satellites are considered very high in:

a. <u>Resolution:</u> the number of pixels for each image.
b. <u>Bit depth:</u> the bits per pixel (bpp).

Hence, the size of a grayscale satellite image may be as high as hundreds of megabytes, and the bit depth is usually represented by 16 bpp most of the time, due to the presence of many details, whereas a few tens of kilobytes with 8 bpp are usually enough to represent a regular grey scale image.

1.2 Satellite Image Compression

Image compression can be identified as decreasing the amount of data required to represent an image, for storage or processing purposes.

1.2.1 The Need for Satellite Image Compression

Since resources are limited onboard small satellites i.e. satellites with a total mass of less than 500 kg, due to the limited capabilities of the hardware components available, as compared to the components on the ground, and since multispectral images are very large, image compression is needed in many space missions to reduce onboard data storage and transmission bandwidth requirements from the satellite to the ground station.

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1.2.2 Satellite Image Compression Categories

Image compression schemes are divided into two main categories:

a. Lossless image compression: The image can be compressed and decompressed without any information loss.
b. Lossy image compression: Allows the image to be reconstructed with a tolerated amount of loss of information. However, it provides a much higher compression ratio than lossless compression, hence it will be used in this work.

High resolution satellite images cannot be dealt with in the same manner as low resolution images due to their large sizes (high resolution and bit depth), especially when taking into consideration the limited resources on-board small satellites. Hence, choosing the suitable compression technique for such images should be carefully considered, in order to achieve high compression ratio (CR) to decrease the bandwidth required to transmit data from the satellite to earth, while maintaining the important scientific information of the image when reconstructed on earth as much as possible.

The Discrete Cosine Transform (DCT) and Discrete Wavelet Transform (DWT) algorithms represent the primary stage for the most commonly used lossy image compression methods, such as JPEG (Joint Photographic Experts Group) and JPEG2000, as shown in Figure (1) that illustrates a basic transform-based lossy image compression system which has 3 main forward steps and 3 inverse steps. All the steps will be discussed in detail in Chapter 2. However, these transform methods have several weaknesses, such as blocking artifacts for DCT-based image compression methods, and high complexity for DWT-based methods.

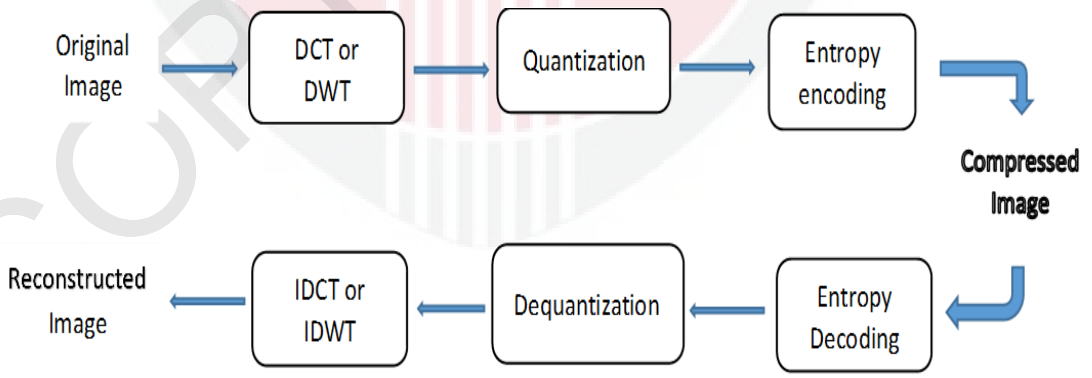

Figure 1.1 : A basic transform-based lossy image compression system

The lossy step in this system is the 2nd quantization step, due to the rounding of coefficients that it includes which cannot be retrieved when the image is reconstructed. Hence, this step is not included in lossless image compression systems.

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1.3 Problem Statement

Due to the limited on-board resources, satellite image compression is needed to decrease the onboard data storage (mass memory) and the downlink bandwidth. Hence, increasing the compression ratio is a primary goal to help decrease these resources.

DCT and DWT-based compression methods have been proven to be the most commonly used lossy image compression techniques onboard satellites. However, these techniques have some drawbacks that should be addressed [1], [2], such as the appearance of blocking artefacts, and the limited values of CR for DCT, while for DWT, the fact that higher values of CR needs higher levels of DWT, which can cause an increase in computational complexity, a degradation of reconstruction quality. Hence a compression method that helps in addressing these drawbacks (without losing the benefits of the DCT or DWT methods) is needed. Hence, several methods that combined DCT and DWT were proposed in previous works to overcome their drawbacks, as in [3], [2], [4] and [5]. However, it was indicated that each method had one or more shortcomings, and none of them were implemented for high resolution satellite images.

The DWT transform method have been proven to be more efficient for compression than the DCT transform. However, it includes embedding the important approximation coefficients within the thresholding and quantization processes. This may lead to a loss of some important information from the satellite image and adds more computations to the compression process.

1.4 Research Objectives

The objective of this research is to simulate an image compression system onboard a small satellite that can improve the compression process, through:

1. Presenting and implementing a proposed hybrid (DWT-DCT) algorithm that can exploit the positive properties, and decrease the effect of the negative properties of the DCT and DWT-based compression methods, to improve the compression process on-board satellites and increase the compression ratio.

2. Employing the zero-padding technique that only deals with the DWT detail coefficients, in the DWT and the proposed hybrid compression methods. This helps to maintain the important information of the satellite image, and decrease the time required for compression.

3. Verifying the feasibility of employing the proposed hybrid method on-board satellites, by comparing it with the standalone DCT and DWT algorithms.

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1.5 Scope of the Study

The current work will present and implement a proposed Hybrid (DWT-DCT) compression method for high resolution satellite images of spectral band 6, simulating an image compression process onboard a small satellite and image decompression at the ground station, with the aim of increasing the compression ratio in order to decrease the data storage (memory) onboard satellites and the RF bandwidth required to transmit data from the satellite to the ground station. This can be achieved while maintaining a reasonably good quality of the reconstructed image at the ground station, preserving its important scientific information through employing the zero-padding technique in the DWT part of the proposed method, as a replacement for the regular DWT thresholding and quantization processes. Due to the absence of these processes, employing the zero-padding technique can also help to decrease the compression time. Hence, the proposed hybrid method can make use of the good characteristics of both the DWT and DCT transform algorithms, while trying to avoid their undesirable characteristics by applying 2D-DCT after 2 levels of 2D-DWT and employing the zero-padding technique.

The proposed method will also be compared with the standalone DWT and DCT methods in order to check the feasibility of using it onboard satellites.

1.6 Thesis Layout

This thesis includes five chapters, in addition to a number of appendices, as follows:

- Chapter 1 includes an introduction to satellite images, satellite image compression and why it is needed, image compression categories, an overview of a basic lossy image compression system, and the current work's problem statement, objectives and scope.
- Chapter 2 describes the literature review of the current work in detail, containing sections that identify satellite-based remote sensing, an overview of the image compression techniques used on-board satellites, main lossy compression algorithms such as the DCT and DWT algorithms, and hybrid algorithms used in image compression are also presented.
- Chapter 3 discusses the methodology used during the current research work.
- Chapter 4 presents the results and comparisons of the current work, discussing them objectively (using charts and tables) and subjectively (visually).
- Chapter 5 gives conclusions of the current work, summarizing its contribution. This chapter also includes several recommendations for future research related to it.

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