ijecs open access www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 4 Issue 11November, 2015 Page No.15036-15040

Performance Analysis of JPEG2000 for Different Wavelets Transforms in satellite images

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Abstract- Nowadays Onboard Image compression algorithm has its own place in all the satellites sent to space for various applications. The images that are obtained by satellites are of huge volume, there arises the need for storing the images onboard. Onboard Image compression is an efficient technique used to reduce the size of an image so that the amount of data stored in the onboard mass memory can be increased. The usage of image compression systems onboard reduces the power and downlink bandwidth required to transmit the image to the ground station. JPEG2000 is one of the most widely used image compression algorithm for observation satellites, due to its high compression ratio. In this paper the performance of JPEG2000 algorithm is analyzed for various wavelet families. The performance of the algorithm is evaluated using the peak signal to noise ratio (PSNR) of the reconstructed image.

Keywords- Onboard image compression, Compression algorithms, JPEG2000, Wavelets

I. INTRODUCTION

The satellites are meant to leave the earth's atmosphere and operate in outer space. Each satellite is designed for a specific application and is placed in either the geostationary or non-geostationary orbits. These satellites capture the images in the outer space, which are used to study about the outer space. The images that are captured by the satellites are of large in number, requires lot of storage space before being transmitted to ground station. The transmission can only be done when it is in range with the ground station. So the images acquired are to be stored onboard. Thus a huge amount of data is to be stored onboard, which becomes a serious problem due to the limited onboard storage capacity of the satellites. This requires an effective compression algorithm to be used, to effectively handle resources available in space missions.

Image compression algorithm compensates the limited on-board resources, like the downlink bandwidth required to transmit the images, reduces the space required to store the images [1]. Most importantly the power required to transmit the images are reduced, which is the main concern in the satellite. Therefore compression algorithm is becoming an important feature to be used by all the space borne satellites. A survey of on-board compression systems developed exclusively by the French Space Agency (CNES) is given in [2]; however, there is no literature source that gives a systematic overview of existing image compression systems across a larger set of space missions.

A much more elaborate survey about the different image compression systems used in the satellites are listed in [1]; which says that the choice of compression algorithm is dependent on the application like remote sensing, weather monitoring, explorer satellite and so on. This paper is structured as follows; Section 2 gives an overview about the image compression techniques and the redundancies present in the image; section 3 list some of the compression algorithms which are used onboard; section 4 elaborates about the JPEG2000 compression algorithm; section 5 is about the simulation results and discussion; section 6 gives the conclusion and section 7 list the references.

II. OVERVIEW OF IMAGE COMPRESSION TECHNIQUES

Image compression reduces the amount of data used to represent an image by reducing irrelevance and redundancies present in an image. Image compression is of two types, lossless and lossy compression. In lossless compression the reconstructed image is almost same as that of the original image. This is preferred in cases where the information content are more important, while in the lossy compression the image is reconstructed with some loss in information content. This loss of information can be expressed as the compression ratio, which varies according the application.

Image compression is possible only due to the presence of redundancies in the image. Several types of redundancy are available, such as coding redundancy, human vision redundancy and inter-pixel redundancy.

(a) Coding redundancy uses different codes to represent a body of information. Information is assigned to a sequence of code words, which vary in length. Huffman coding and arithmetic coding is the frequently used algorithms to reduce the coding redundancy present in an image.

(b) Human vision redundancy uses the fact that human eyes are not so sensitive towards the high frequency information in an image. This is achieved by means of quantizing the image.

DOI: 10.18535/Ijecs/v4i11.30

(c) Inter-pixel redundancy uses the correlation between the pixels. The pixel information can be predicted from the neighbouring pixels by using prediction or transformation based compression technique. Transformation based compression transforms the image from spatial domain to compress the image. DCT and DWT are frequently used transformations. In prediction based the current pixel information is obtained from the neighboring pixels as in differential pulse code modulation (DPCM) [1].

The redundancies listed above are used to compress the original image, but the image compression system which is to be used onboard is to satisfy the following requirements

- It should work with **2D, 3D** as well as non-frame based imagery data so as to suit for various types of imagery instruments.
- **Adjustable data rate or image quality** for different space missions. Some requires a fixed data rate; other may need a fixed image quality which varies the bit rate used.
- Capable of processing a wide range of **quantization levels** varying from 4 to 16 bit per sample.
- Should allow **progressive transmission**, i.e., to transmit images in several pieces.
- To provide maximum **error containment**.

A basic image compression system Fig. 1 consists of spatial transformation, quantization and entropy coding operations to obtain the compressed image, whose reverse operation is performed in order to obtain the reconstructed image. The following section briefs the different image compression systems used on board.

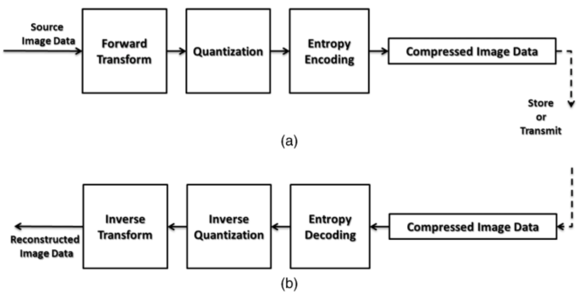

Fig.1. Architecture of an image compression system (a) encoder (b) decoder

III. ONBOARD IMAGE COMPRESSION SYSTEMS

Many of the space missions are accompanied with any of the image compression systems on board. These compression systems can be divided into four main groups. First is the transformation based compressions like DCT and DWT which occupies most of the space missions. Prediction based compression systems are next, like DPCM, JPEG-LS, JPEG and so on. Rice based and BTC (Block truncation coding) occupies a small percentage. A comprehensive literature survey of more than 40 space missions have been listed out [1]

The BTC is a lossy compression technique which was first implemented onboard in PoSAT-1(SSTL - Portugal 1993) [3], Tsinghua-1(SSTL-THU2000) [4] and Tiung SAT (SSTL-Malaysia2000) [5]. These satellites are mainly used for earth observation. The DPCM is the first image compression algorithm which is deployed onboard in SPOT1 (CNES1986) to SPOT4 [2] satellites, which is mainly used for earth observation.

Later the transform techniques are used onboard. The DCT based technique was deployed in Clementine (NASA 1994), Cassini probe (US/EU 1997) [2]. The DCT based compression algorithm with compression ratio of 2.8 or 3.2 is used in The THEOS (CNES - Thailand2008) [6]. The JPEG baseline compression system is used in SUNSAT (South Africa 1999) [7], Proba-1 (ESA2001) [8] and Beijing-1(SSTL – China 2005). The JPEG2000 compression technique is implemented in IMS-1 (ISRO2008) [9], RASAT (Turkey 2009) and X-SAT (Singapore 2009) [1]. It is clear that the lossy compression technique is used in earth observation application, due to the highest compression ratio that can be obtained. In the following section the JPEG2000 algorithm is explained clearly.

IV. JPEG2000 COMPRESSION SYSTEM

The JPEG2000 encoder is shown in Fig. 2. First the source image is DC level shifted, by subtracting all the samples of the image by 2^{p-1}, where p is the component precision.

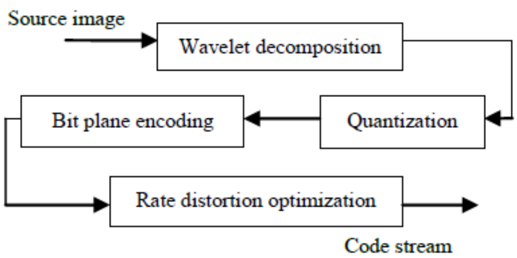

Fig. 2. JPEG2000 encoder

The discrete wavelet transform is applied on the level shifted image coefficients, implemented by Daubechies 9-tap/7-tap filter [10], which decompose the image into different resolution levels. After taking transform all the coefficients are quantized using different quantization step size for different levels.

$$q_b(u,v) = sign\left(a_b(u,v)\right)\left\lfloor \frac{|a_{b(u,v)}|}{\Delta_b} \right\rfloor \quad (1)$$

$$\Delta_b = BSS * \sqrt{\frac{1}{2^{(2*l)}}} \quad (2)$$

Where BSS is the basic step size, l is the decomposition level, is the quantization step size [11], is the transformed coefficient of the sub band b, is the quantized value. After quantization each sub band of different resolution levels are further divided into code blocks of size smaller than the sub bands. Then bit plane coding is applied separately on each code block. It operates on the bit plane in the order of decreasing importance, to produce an independent bit stream for each code block. Each bit plane is encoded in a sequence of three coding passes namely, significance propagation pass, magnitude refinement pass, clean up pass [12].

DOI: 10.18535/Ijecs/v4i11.30

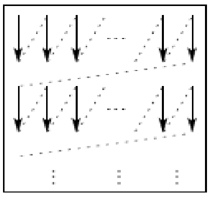

Fig. 3. Scanning order

After bit plane encoding, rate distortion optimized truncation is done on coded bit streams. The EBCOT algorithm produces a bit stream with many useful truncation points. The bit stream can be truncated at the end of any coding passes to get desired compression ratio. The truncation point of every code block is determined by rate-distortion optimization [12]. At the decoder side bit plane decoding, dequantization and wavelet reconstruction is done to reconstruct the image. The standard JPEG2000 compression algorithm uses 9/7 tap filter but in the next section the JPEG2000 algorithm was evaluated for different transforms of wavelet family.

V. Simulation Results and Discussion

The JPEG2000 compression algorithm is one of the most widely used compression algorithm for the remote sensing applications. The standard JPEG2000 uses Daubechies 9/7 tap filter whose coefficient is given in [10]. The JPEG2000 uses the wavelet families to compress the image. In this paper we are evaluating the performance of the JPEG2000 for other wavelet families as well. We have taken db1, db5, db9/7 filter from Daubechies family, symlets4 and biorthogonal2.4 for comparison.The original satellite image is taken, which is compressed using different wavelet families. The haar transform is the db1 which is applied for the four different images whose PSNR values are shown in the Table: 1. the original and the reconstructed image of geoeye-1-satellites-vatican-city using db1 transform is shown in Fig. 4.

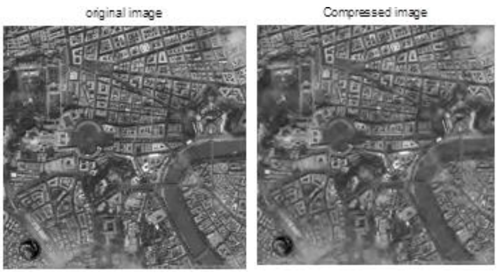

Fig. 4. Original and reconstructed image of geoeye-1-satellites-vatican-city using db1

The table 1 clearly shows that the db1 works better based on the image. If the image has many fine details then the reconstructed image is not that much exactly as that of original image. The peak signal to noise ratio of the reconstructed image is calculated as

$$\text{PSNR(dB)} = 10 * log_{10}\left(\frac{255^2}{MSE}\right) \quad (3)$$

where,

MSE = (original image—reconst image) ^{2} (4)

The table 2 gives the comparison of db5 for the given image. Here the reconstructed image is better than that of the db1 and so the PSNR value which is slightly higher than that of the db1 transformed image.

The table 3 to table 5 gives the comparison table for db9/7, symlet4 and biorhogonal2.4. The reconstructed image using sym4 and bior2.4 much better when compared to the other two transforms. The original and reconstructed images are shown below.

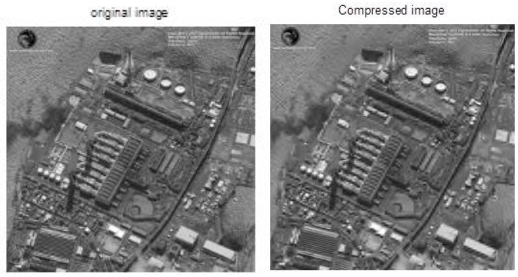

Fig. 5. Original and reconstructed image of worldview-1-satellite-image-yokohama-japan using bior2.4

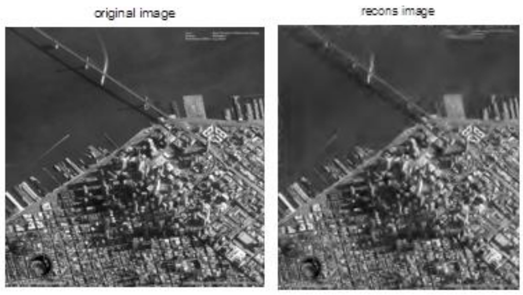

Fig. 6. Original and reconstructed image of pleiades-1-san-francisco using db 9/7 tap filter

The db 9/7 tap filter output is shown in table 3, which is slightly better than all the other wavelets. It shows a slight increase in the PSNR values of the reconstructed image which is clearly evident in the table.

TABLE 1: COMPARISON OF JPEG2000 algorithm using db1 wavelet for different images

Bits per pixel	**PSNR (db) for db1 wavelets**			
	geoeye-1-Vatican-city	**pleiades-1-San-Francisco**	**SPOT 7- Fiji Island**	**worldview-1-yokohama-Japan**
0.4	21.6003	21.300	25.2754	22.0637
0.6	22.5600	22.4515	27.2264	23.0583
0.8	23.6743	23.9704	28.7959	24.0639

TABLE 2: COMPARISON OF JPEG2000 algorithm using db5 wavelet for different images

Bits per pixel	**PSNR (db) for db5 wavelets**			
	geoeye-1-Vatican	**pleiades-1-San-Francisc**	**SPOT 7 - Fiji Island**	**worldview-1-yokohama-**

	-city	o		Japan
0.4	22.5423	22.3743	26.7308	23.1323
0.6	23.6513	23.4778	28.6975	24.1604
0.8	25.0256	25.1598	30.3127	25.4290

TABLE 3: COMPARISON OF JPEG2000 algorithm using db9/7 wavelet for different images

Bits per pixel	PSNR (db) for db9/7 wavelets			
	geoeye-1-Vatican-city	pleiades-1San-Francisco	SPOT 7 - Fiji Island	worldview-1-yokohama-Japan
0.4	22.4873	22.4250	27.1490	22.5502
0.6	23.8957	24.0364	28.7734	23.8645
0.8	25.5406	25.9594	30.1331	25.4248

TABLE 4: COMPARISON OF JPEG2000 algorithm using sym4 wavelet for different images

Bits per pixel	PSNR (db) forsym4 wavelets			
	geoeye-1-Vatican-city	pleiades-1San-Francisco	SPOT 7 - Fiji Island	worldview-1-yokohama-Japan
0.4	22.5575	22.1566	26.8371	23.0192
0.6	23.5434	23.3853	28.8784	24.0908
0.8	24.9805	25.1139	30.2209	25.3033

TABLE 5: COMPARISON OF JPEG2000 algorithm using bior2.4 wavelet for different images

Bits per pixel	PSNR (db) forbior2.4 wavelets			
	geoeye-1-Vatican-city	pleiades-1San-Francisco	SPOT 7 - Fiji Island	worldview-1-yokohama-Japan
0.4	22.1641	22.1641	26.4975	22.8747
0.6	23.2300	23.2300	27.7713	23.7783
0.8	24.3847	24.3847	29.0561	24.5807

VI. CONCLUSIONS

In this paper the JPEG2000 compression technique is analyzed using different wavelet families and their results are compared in table1 to table 5. It is clear that the Daubechies 9/7 tap filter output is much clear than the other transforms which are considered for comparison. The PSNR value is much better when compared to the other transforms, which is evident in table. But even though the PSNR value for db9/7 filter is slightly smaller for some images, the reconstructed image quality is much better when compared to the other transform. Thus for image compression of satellite images the Daubechies 9/7 filter works better when compared to the other wavelet families.

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