Image data compression with CCSDS Algorithm in full frame and strip mode

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Abstract-Efficient sensor and detector at payloads creates large volume of data at high data rate. Amount of compression is essential to handle this situation. CCSDS (Consulative Committee for Space Data System) recommendation specifies image data compression standard that is based on DWT (Discrete wavelet transform) and BPE (Bit plane encoding). Objective of the paper is to analyze the performance of CCSDS image data compression algorithm for strip and frame mode. Algorithm suitable for the lossy and lossless both type of compression. The Recommendation supports two choices of DWT: an integer and a floating point DWT. The integer DWT is capable of providing lossless compression, and has lower implementation complexity. While floating point DWT provides improved compression effectiveness at low bit rates, but requires floating point calculations and cannot provide lossless compression. Algorithm supports 8,10,12,16 bit images. The compression scheme performs on a suite of test images acquired from spacecraft instruments. Simulation result shows 1st, 2nd and 3rd level DWT results. Compression ratio and different parameters are observed for this algorithm.

Keywords— Discrete Wavelet transforms, Image compression, CCSDS, Wavelets, Wavelet transform.

INTRODUCTION

With effective sensor and detector large amount of information to be collected, buffered, and transmitted. To help this situation CCSDS (consultative committee for space data segment) has developed the algorithm specific for the space application. Initially CCSDS has developed the lossless algorithm that is used for lossless compression only. Then it developed image data compression algorithm [6] that supports both loss less and lossy compression. CCSDS image data compression scheme is similar to the JPEG 2000 but it is differ in the some issues. Paper demonstrates CCSDS image data compression for the frame and strip mode . If entire image is compressed as one segment than it is frame mode while image is compressed in step by step is called strip mode. In strip mode as number of segments are more so more amount of header and footer is require than lengthen the code.

CCSDS ALGORITHM DESCRIPTION

DWT (Discrete Wavelet Transform)

Wavelets are used for CCSDS image data compression algorithm recommendation. Their irregular shape lends them to analyze signals with discontinuity's or sharp changes, while their compactly supported nature enables temporal localization of a signal's features.

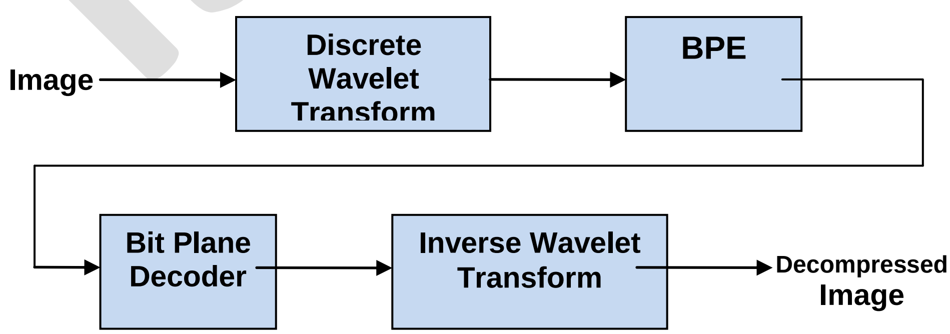

Fig-1 Algorithm

The recommended algorithm consists of two functional modules as depicted in Figure 1, a Discrete Wavelet Transform (DWT) module that performs decorrelation, and a Bit-Plane-Encoder (BPE) that encodes the decorrelated data. The wavelets Transforms can be interpreted in two ways. Vector space decomposition and Filter bank approach. The former one describes the wavelet transform as a projection of a signal onto a series of basis functions called the wavelet basis. Just like the Fourier series, where the signal is decomposed into trigonometric sine & cosine basis functions, the wavelet transform decomposes the signal into a basis called the wavelet.

FORMULATION

For preprocessing required by lossy and lossless compression, different methods and formulae are applied. For lossless compression Integer Discrete Wavelet Transform is applies whereas in Lossy compression Floating Discrete Wavelet Transform is applied. Also for this recommendation a three level transform of coefficients is done. These are explained as following. Both are done using 9/7 tap filters.

- **Integer Discrete Wavelet Transform (For Lossless Compression) Forward DWT**

In this case we do a non-linear approximation of 9/7 tap Integer DWT. Data is fed into the program in a row-wise fashion first then column-wise. A 1-dimentional wavelet transform maps a vector to a set of wavelet coefficients, one high pass set, D_j, and one low pass set C_j. This completes a one level forward Integer Discrete Wavelet Transform. This process is repeated two more times to achieve the required three-level wavelet transform of the image. The equations used to compute this transform are as follows. Here we have considered a row size of N and a row containing elements from 0 to N-1.

$$D_0 = x_1 - \left\lfloor \frac{9}{16}(x_0 + x_2) - \frac{1}{16}(x_2 + x_4) + \frac{1}{2} \right\rfloor \qquad (1)$$

$$D_j = x_{2j+1} - \left\lfloor \frac{9}{16}(x_{2j} + x_{2j+2}) - \frac{1}{16}(x_{2j-2} + x_{2j+4}) + \frac{1}{2} \right\rfloor \quad for\ j = 1,2,\ldots,N-3 \qquad (2)$$

$$D_{N-2} = x_{2n-3} - \left\lfloor \frac{9}{16}(x_{2N-4} + x_{2N-2}) - \frac{1}{16}(x_{2N-6} + x_{2N-2}) + \frac{1}{2} \right\rfloor \qquad (3)$$

$$D_{N-1} = x_{2N-1} - \left\lfloor \frac{9}{8}(x_{2N-2}) - \frac{1}{8}(x_{2N-4}) + \frac{1}{2} \right\rfloor \qquad (4)$$

$$C_0 = x_0 - \left\lfloor -\frac{D_0}{2} + \frac{1}{2} \right\rfloor \qquad (5)$$

$$C_j = x_{2j} - \left\lfloor -\frac{D_{j-1} + D_j}{4} + \frac{1}{2} \right\rfloor \quad for\ j = 1,2,\ldots,N-1 \qquad (6)$$

- **Floating discrete wavelet transform (for lossy compression) forward (analysis)**

In this case we do 9/7 tap Floating DWT. A 1-dimentional wavelet transform maps a vector to a set of wavelet coefficients, one high pass set, D_j, and one low pass set C_j.This completes a one level forward Discrete Wavelet Transform. This process is repeated two more times to achieve the required three-level wavelet transform of the image. The equations used to compute this transform are similar to those of convolution of the input signal with the filter. Hence the filter coefficients are to be specified as well. The coefficients for forward transform are known as analysis filter coefficients and are stated in table 1.

Table -1: Filter coefficient

i	Analysis Filter Coefficients	
	Lowpass Filter h_i	***Highpass Filter g_i***
0	0.852698679009	-0.788485616406
±1	0.377402855613	0.418092273222
±2	-0.110624404418	0.040689417609
±3	-0.023849465020	-0.064538882629
±4	0.037828455507	

And the equations used are as follows

$$C_j = \sum_{n=-4}^{4} h_n x_{2j+n} \qquad j0,1,\ldots,N-1 \tag{7}$$

$$D_j = \sum_{n=-3}^{3} g_n x_{2j+n+1} \qquad j = 0,1,\ldots,N-1 \tag{8}$$

In the above equations h_n is the set of low pass filter coefficients and g_n are the set of high pass coefficients.

BPE(bit plane encoder)

The BPE takes DWT coefficient data from the DWT coefficient buffer, encodes coefficient data, and places the encoded output in the compressed data stream. The wavelet coefficients are either rounded to the nearest integer (when the floating-point transform has been used), or scaled using the weighting factors (when the integer transform has been used). The Bit Plane Encoder (BPE) processes wavelet coefficients in groups of 64 coefficients referred to as blocks. A block is the basic building unit in BPE coding. A block loosely corresponds to a localized region in the original image. Information pertaining to a block of coefficients is jointly encoded by the BPE. A block consists of a single coefficient from the LL3 sub-band, referred to as the DC coefficient, and 63 AC coefficients. The AC coefficients in a block are arranged into three families, F_0, F_1 and F_2.

Structure of the coded segment

Segment header: Four types of segment headers are specified in the recommendation. Header 1 is mandatory and remaining parts are optional. Header mainly include the compression option.

Quantized representation of DC coefficient information: simple differential coding method can be used to exploit inter-block correlation among DC coefficients. Rice code algorithm is used for the differential coding.

Bit depths of AC coefficient blocks: the BPE encodes the sequence of BitDepthAC of the different blocks. The value of BitDepthACBlockm indicates the number of bits needed to represent the largest magnitude of AC coefficient in the m^{th} block. Figure 2 represent how the block is formatted from the DWT coefficient.

Bit planes of AC coefficients: The last step of the BPE stage is bit-plane coding of the AC coefficients. Each wavelet coefficient is represented in binary using one sign bit and R-1 bits to specify the magnitude. Here, R represents the maximum number of bits that may be needed to represent a DWT coefficient, and thus R is not a parameter that can be arbitrarily set by the user, but rather the value of R is determined by the image pixel bit depth and choice of DWT employed.

RESULTS

- **Results for full frame compression**

Number of blocks per segment can be controlled in CCSDS-IDC. There are S number of blocks in the segment. Choice of S affects the memory requirement, robustness to data errors and compression effectiveness. Image with width W and height H generates $\lceil W/8 \rceil . \lceil H/8 \rceil$ DWT coefficient blocks. The blocks can be thought of as and array with width $\lceil W/8 \rceil$ and height $\lceil H/8 \rceil$. When block size s = $\lceil W/8 \rceil . \lceil H/8 \rceil$ entire image is compressed as a single segment and that compression is called full-frame compression

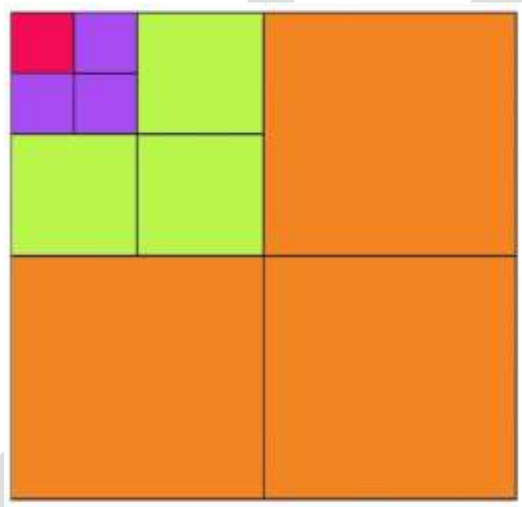

Figure: Example of Frame compression

- **Results Strip compression**

When segment size S= $\lceil W/8 \rceil$ each image is loosly corresponds to a thin horizontal strip of image. This is called strip compression. This type of compression is suitable for the push-broom type of sensors. Advantage of strip compression is that there is no need to store a complete frame of image. thus it can lead to memory efficient implementation that is convenient to push-broom sensors

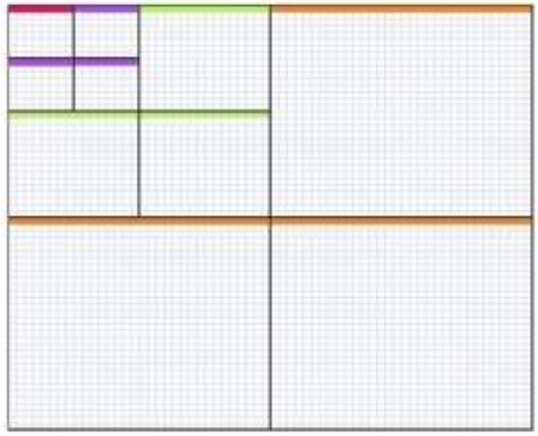

Figure: Example of Strip compression

Table 2: Result for Lossless full frame compression

Serial No	Image name	Segment size	Bit depth	CR	RMSE	PSNR	PPM
1	Moon	4096	8	1.4	0.4	57	89
2	Ocean	16384	10	3.2	1.04	66	75.5
3	Foc	4096	12	5.5	0.98	72.57	85
4	Sunspot	4096	12	2.3	0.1	92.24	99
5	Europa	4096	16	1.8	0	inf	100
6	Galaxy	4096	8	1.5	0.54	82.13	88
7	Spiral	4096	8	2.1	0.74	77.13	90
8	Mars	4096	8	1.3	0.01	94	96

Table 3: Result for Lossy full frame compression

Serial No	Image name	Segment size	Bit depth	CR	RMSE	PSNR	PPM
1	Moon	4096	8	1.58	1.01	46.54	63
2	Ocean	16384	10	3.42	1.5	56	65.40
3	Foc	4096	12	5.69	1.0	72	71.95
4	Sunspot	4096	12	2.56	1.7	43.49	61.58
5	Europa	4096	16	1.93	1.22	94.03	65.68
6	Galaxy	4096	8	1.82	1.14	45.13	67.7
7	Spiral	4096	8	2.3	0.2	54.18	86.99
8	Mars	4096	8	1.5	1.04	80	85

Table 4: Result for Lossless strip compression

Serial No	Image name	Segment size	Bit depth	CR	RMSE	PSNR	PPM
1	Moon	64	8	1.52	1.18	45	62
2	Ocean	256	10	3.32	1.58	55	64
3	Foc	128	12	5.58	1.07	68	70.1
4	Sunspot	64	12	2.54	1.76	42.15	60
5	Europa	64	16	1.67	1.2	93	64
6	Galaxy	64	8	1.6	1.09	44.13	65
7	Spiral	64	8	2.2	0.5	52.12	85
8	Mars	64	8	1.2	0.54	92	95

Table 5: Result for Lossy strip compression

Sr. No	Image name	Segment size	Bit depth	CR	RMSE	PSNR	PPM
1	Moon	64	8	1.52	1.18	45	62
2	Ocean	256	10	3.32	1.58	55	64
3	Foc	128	12	5.58	1.07	68	70.1
4	Sunspot	64	12	2.54	1.76	42.15	60
5	Europa	64	16	1.67	1.2	93	64
6	Galaxy	64	8	1.6	1.09	44.13	65
7	Spiral	64	8	2.2	0.5	52.12	85
8	Mars	64	8	1.2	0.54	92	95

CONCLUSION

Paper shows the method used for the image data compression for spacecrafts. Algorithm use the Discrete wavelet transform. It gives better results than DCT. Algorithm is suitable for the Lossless as well as lossy compression techniques. Interger and floating point arithmatic is used for the lossless and lossy compression respectively. Result table shows the result for the lossless as well as lossy compression for the frame compresssion and strip compression. For frame compression entire image is compressed in a single segmement while in strip compression strip by strip compression is performed. There is trade off between the selection of strip based and frame based compression. Minimum value of S=16. If the segment size is very small, total number of segment in the image wiil be large and it will degrade the compression effectiveness. Because the larger number of header are there but if any one segment is lost then there is considerable loss of information. while in strip based compression if any one segment is lost there is small amount of loss. Thus selection of frame based and strip based compression depends on the memory requirements. number of headers are included with each segment.

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