A comparison of Satellite Image Compression methods in the Wavelet Domain

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Abstract. Better resolution of remotely sensed satellite images will make images clearer and interpretation easier but will increase the total volume of data that has to be managed. In order to reduce data volume for easier satellite communication transmission and reduce the total volume of data needed to be stores, the images should be compressed. Image compression in wavelet domain can be used for both lossy or lossless compression. Four major compression methods are available using the wavelet domain, i.e. CCSDS, Wavelet, Bandelet, and JPEG 2000. Some optical satellite images, were used as input data in simulation software which analyzed and compared the four compression methods in the wavelet domain. The result showed that the CCSDS method yielded the fastest compression and decompression time, but the Bandelet method retained better image quality when reconstructing original images or approximations of them compared to CCSDS. The JPEG 2000 method delivered better quality images than CCSDS for low bit rate. In summary at a rate of 0.25 bpp, CCSDS is 15 times faster than Bandelet and 3 times faster than JPEG2000. However, CCSDS quality is lower by up to 8.77% compared with Bandelet and up to 13.64% compared with JPEG2000.

Keywords. Remote Sensing, Satellite Images, Wavelet Domain, CCSDS, Bandelet, Wavelet, JPEG 2000.

1. Introduction

At present, remotely sensed satellite imagery is getting better in terms of spatial, temporal, and spectral resolution, as well as data rate as shown in Table 1. This table illustrates the increase in compression requirements. With this wealth of information, problems arise in handling very large volumes of data, at each stage of image acquisition process. To reduce data volume and facilitate the transmission of satellite communication and storage, we need to apply compression techniques to satellite image data.

Large multispectral imageries add to the computational burden from the perspective of data storage and transmission, so data compression becomes an important and urgent goal. At the same time, it is very expensive to obtain multispectral data, moreover these data are often used for further analysis and processing operations such as classification or target detection. Therefore, only by using lossless compression technology, we can ensure reducing the volume of data without losing any information. However, for higher compression, lossy image compression can be used, with acceptable loss of information.

Table 1. Resolution and bit rate of some earth observing satellites.

Satellites	Swath (km)	Spatial Resolution (m)	Data rate (Mbps)
SPOT 4	60	10	32
SPOT 5	60	2.5	128
PLEIADES	20	0.7	4500
IKONOS	11	3.2	320
QUICK BIRD	18	2.6	320

The discrete wavelet transform associated with sub-band coding provides high image compression ratio. Although the wavelet transform performs well on smooth areas, the wavelet representation of edges is not sparse [1]. Indeed, wavelet coefficients have high magnitude around the edges and correlations between those coefficients remain. Therefore, great efforts have been made in the design of coding schemes to handle the redundancy near the edges. The significance propagation passes in EBCOT coder [2, 3], which is part of the JPEG2000 standard, has the same goal. The CCSDS (Consultative Committee for Space Data Systems) recommendation for image data compression [4, 5] specially targets on-board spacecraft compression. In this recommendation, wavelet coefficient redundancy is exploited in a tree-like coding scheme.

Image compression in wavelet domain had been widely used within past decades. In the year 2000 Joint Photographic Experts Group (JPEG) committee created newest technology known as JPEG2000, is one of the popular image compression standards which is using wavelet as core transform. For satellite image proposed by CCSDS in their standard about image data compression in November 2005, also using wavelet transform. Both standard using different posts processing in wavelet domain. CCSDS using bit plane encoder that is referred to rice entropy coder.

In 2007, Stéphane Mallat, Gabriel Peyré introduce Bandelet transform exploits geometric regularity that is found in images by constructing orthogonal vectors that are elongated in the direction where the function has a maximum of regularity. Before that, in 2000 Bandelet transform of Pennec and Mallat links the significant wavelet coefficients along a discontinuity and represents it as a smooth 1-D curve geometry computed from the image.

In 2008, X. Delaunay, *et al* writes a paper about directional decorrelation of wavelet coefficients for satellite image compression. The objective is to prove that is possible to enhance the compression performance by further decorrelation of the wavelet coefficients. They first analyse the directional bases for the grouping Bandelet transform and propose new bases which are better suited to de-correlate the wavelet coefficients in the different sub-bands. Review on how the directional Bandelet bases have been built as well as the practical Bandelet compression and analyse the ability of the Bandelet bases to capture directional correlations. Based on the observation, propose extended grouping configurations and build new dictionaries of orthogonal bases which better de-correlate wavelet coefficients. Furthermore, even better decorrelation is obtained with bases learned by Principal Component Analysis (PCA). The research continues in 2009 in their second paper about post processing in wavelet domain that proposes a novel compression scheme with a tuneable complexity rate and distortion trade-off, this paper also compare post processing method with JPEG2000 and CCSDS image data compression.

All post processing in wavelet domain is aim to exploit remain redundancies between the wavelet coefficients to achieve higher compression and higher quality. Finding efficient geometric representations of images is a central issue to improving image compression [6].

The main satellite on-board compression constraints are strip-based input format produced by push-broom acquisition mode, limited downlink capacity and limited on-board computational capacity. First, as the satellite travels Earth surface up and down, the optical sensors produce an image of fixed width but with a virtually endless length. Therefore, this image has to be compressed and transmitted during its acquisition. The post-transform compression scheme is intended to reduce these dependencies while maintaining a low complexity [7].

Coders that produce embedded bit-streams such as the BPE of the CCSDS [4, 5] are thus recommended. Bit-rate regulation is then possible by simple truncation of the bit-stream whatever the bit-rate. On the contrary, as mentioned in the Introduction, a reliable tuning of JPEG2000 bit rate has a high computational cost [8]. Indeed, JPEG2000 encoder imposes specific truncation points.

The objective of the research is to implement a simulation in MATLAB, analyze and compare the compression method in wavelet domain. Image compression in the wavelet domain will be used to achieve lossy and lossless compression.

The CCSDS image data compression standard would be used to compare with other methods that use post transformation in wavelet domain such as Bandelet approach in literature [1, 7, 9, 10] and also compare to JPEG2000 standard. The algorithm will be implemented in MATLAB and/or C language. Satellite imageries will be used to test the program. The result of this simulation will analyse the time consuming, compression ratio and also PSNR (reconstructed image quality). This study also analyse using a DWT integer for lossless compression, to compare between CCSDS image data compression and JPEG2000 standard.

2. Method

The research methodology can be seen in the figure 1 below.

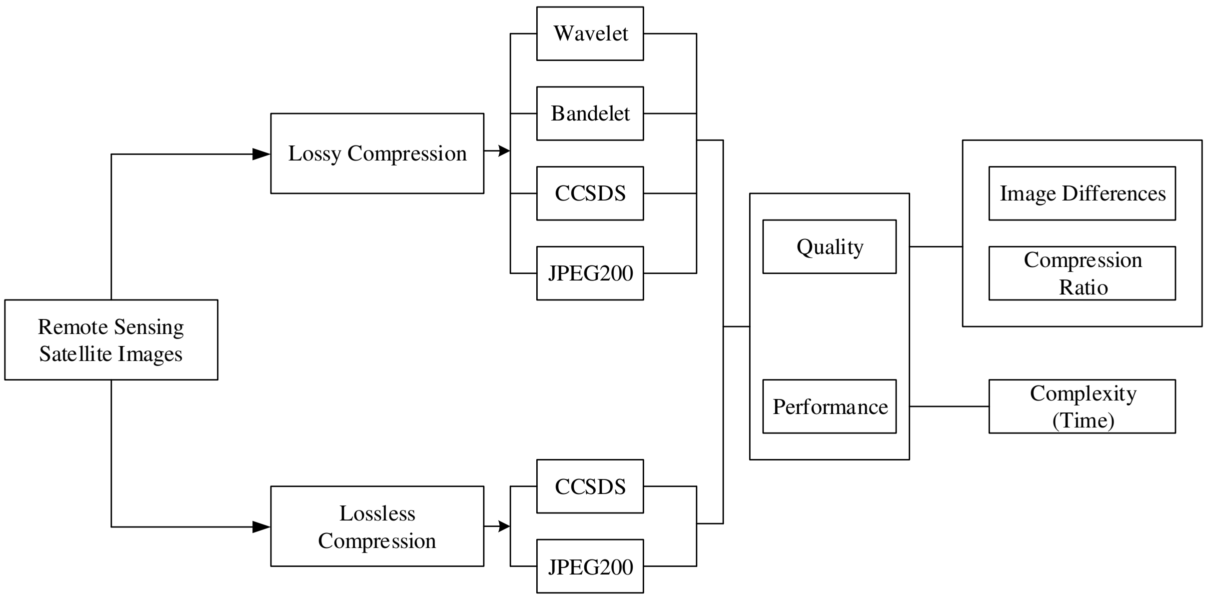

Figure 1. Research methodology.

In this research, there are three important performance parameters that should be considered:

- Compression Ratio; this parameter show how well the compression scheme is. This can also be indicated by bpp (bit per pixel).
- PSNR (Peak Signal to Noise Ratio); this parameter is to show the differences between original image and the image after compression and decompression. For lossless PSNR is infinity.
- Time consuming; this parameter will show the complexity of the compression scheme.

Images used to test the software are a standard processing image called Lena image and other 5 satellite images. Lena's image is a natural image as a comparison with satellite images. Lena image has entropy 7.4456 bit/symbol with size is 512x512 pixels. Satellite image 1 has entropy 5.3443 bit/symbol with size 512x512 pixels. Satellite image 2 has entropy 7.1624 bit/symbol with size 512x512 pixels. Satellite image 3 has entropy 6.9438 bit/symbol with size 512x512 pixels. Satellite

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image 4 has entropy 6.8802 bit/symbol with size 512x512 pixels. Satellite image 5 has entropy 6.8631 bit/symbol with size 512x512 pixels.

Figure 2. Lena image.

Figure 3. Satellite image 1 (color & 8 bit gray level).

Figure 4. Satellite image 2 (color & 8 bit gray level).

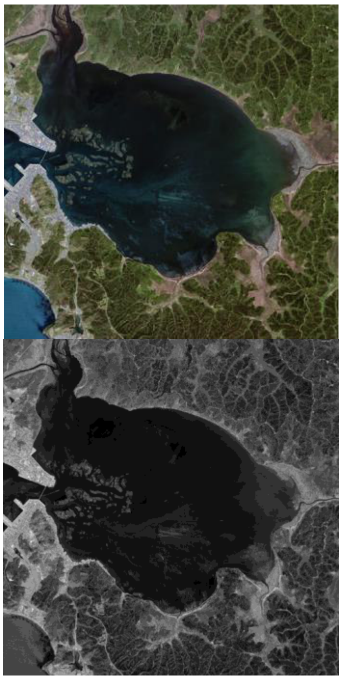

Figure 5. Satellite image 3 (color & 8 bit gray level).

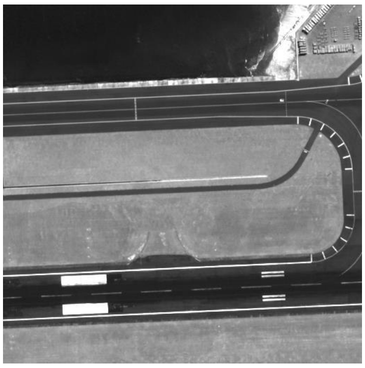

Figure 6. Satellite image 4.

Figure 7. Satellite image 5 (color & 8 bit gray level).

The implementation will create a graphical user interface in MATLAB. The GUI will be as in the Figure 3.5. The Six compression algorithms mentioned above are used here and each method can be entered with related parameters. There are four parts in the main interface, namely Parameters, Original images, Reconstruction Images and Image Differences. The Parameter part is for text about the method used, input threshold or bpp, image name, size, entropy, PSNR error, compression ratio, compression time and decompression time. Original image will display the image before it is processed and immediately displayed after opening the image using open button. Reconstruction part will display the reconstructed image after the start button is clicked. Image differences part will show the differences between the original image and reconstructed image after the start button is clicked. There are seven buttons at the top which are open, method, input parameter, start, comparison, tool and quit button. The open button is used to open a new image. The method button is used to choose what compression method we want to use. The input parameter button is used to input the threshold or bpp depending on the chosen algorithm. The Start button is used to start calculating the compression and displaying the reconstructed image and image differences. The comparison button is used to compare between all lossy compression algorithms. The tool button is used to convert colour image to 8-bit gray-level image of specified size. The quit button is used to close the interface. There is one check box option, which is save check box, used to choose if we want to save the result image both reconstructed and image differences.

3. Results

The complete results of compression are shown in the table 2. The contents of the table are an image entropy, reconstructed image quality shown by PSNR, compression time and decompression time. This table is a summary for lossy image compression with 0.25 bpp (bit per pixel) using four different algorithms, i.e. Wavelet, Bandelet, JPEG 2000, and CCSDS image data compression. Table 3 shows the compression result for lossless compression using JPEG 2000 lossless compression and CCSDS lossless image data compression. Content of the table is entropy of image and compression ratio.

Table 2. Complete lossy image compression results

		PSNR (dB)				Comp. time (s)				Decomp. Time (s)			
Image name	Entropy	1	2	3	4	1	2	3	4	1	2	3	4
Lena	7.4456	31.6441	32.0215	32.2512	31.9718	1.0	3.8	0.8	0.7	1.0	1.5	0.6	0.3
Sat. image 1	5.3443	35.5997	35.4148	35.8153	34.8422	1.2	4.5	0.8	0.3	1.2	1.9	0.7	0.3
Sat. image 2	7.1624	29.1795	29.408	30.3799	28.3917	1.0	4.0	1.2	0.4	1.0	1.6	0.8	0.4
Sat. image 3	6.9438	27.8404	27.9346	28.1388	28.1241	1.4	4.9	1	0.4	1.4	2	0.7	0.4
Sat. image 4	6.8802	31.3946	33.0257	34.2405	30.1296	1.0	3.9	0.8	0.6	1.0	1.6	0.6	0.4
Sat. image 5	6.8631	31.2398	31.4861	31.6130	31.0028	1.0	4.1	0.8	0.4	1.0	1.6	0.6	0.3

Annotation:
1 = Wavelet 3 = JPEG 2000
2 = Bandelet 4 = CCSDS image data compression

Table 3. Lossless image compression results.

		Compression ratio		Compression Time (s)		Decompression Time (s)	
Image name	Entropy	JPEG 2000	CCSDS	JPEG 2000	CCSDS	JPEG 2000	CCSDS
Lena	7.4456	1.8543	1.8023	1.59	0.75	0.59	0.44
Sat. image 1	5.3443	3.2612	3.1519	0.95	0.80	0.53	0.38
Sat. image 2	7.1624	2.0283	1.902	0.75	0.63	0.62	0.45
Sat. image 3	6.9438	1.7252	1.7119	0.68	0.54	0.45	0.46

Sat. image 4	6.8802	2.109	1.9758	0.97	0.53	0.68	0.47
Sat. image 5	6.8631	1.8932	1.8562	0.63	0.59	0.63	0.43

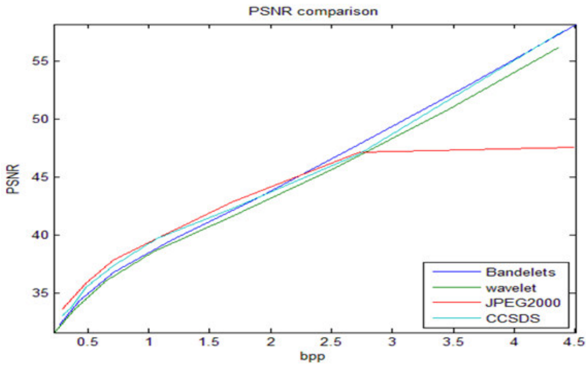

Figure 8. Lena image.

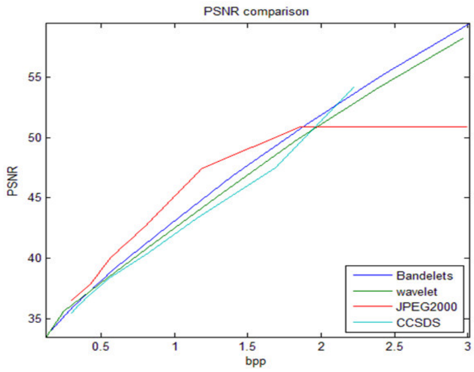

Figure 9. Satellite image 1 quality comparison.

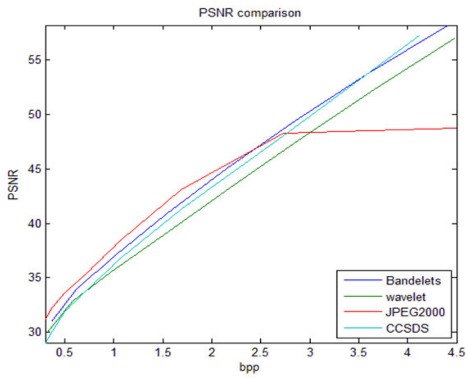

Figure 10. Satellite image 2 quality comparison.

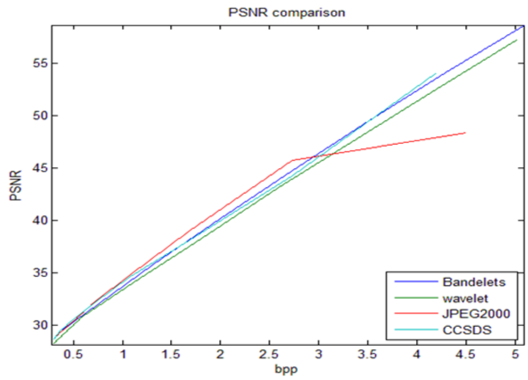

Figure 11. Satellite image 3 quality comparison.

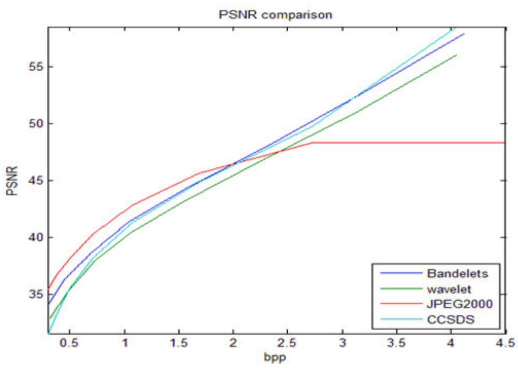

Figure 12. Satellite image 4 quality comparison.

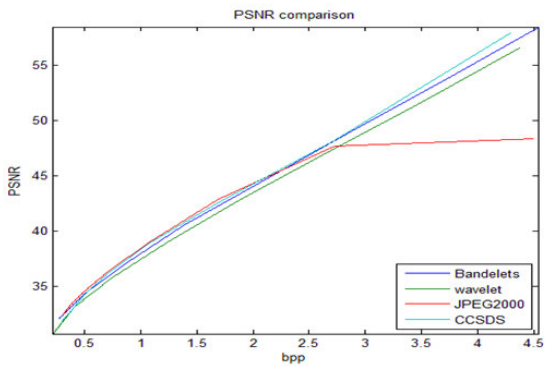

Figure 13. Satellite image 5 quality comparison.

4. Discussion

4.1. Compression ratio and Compression quality

Image quality in lossy compression refers to the quality of the reconstructed image compared to original image. Compression ratio is related to bit rate or bit per pixel, because we use 8 bit per pixel original image so bit rate has to be smaller than 8 to achive higher compression ratio. Lower bit rate means higher compression ratio.

Image compression using Bandelet has higher quality compare to wavelet compression for most of the image. For Lena image with compression at 0.25 bpp has 1.18% better quality in PSNR, for satellite image 1 has 0.52% lower quality in PSNR, for satellite image 2 has 0.78% better quality in PSNR, for satellite image 3 has 0.34% better quality in PSNR, for satellite image 4 has 4.94% better quality in PSNR, for satellite image 5, has 0.78% better quality in PSNR. Compare to CCSDS image data compression, Bandelet mostly has higher compression quality for compressing at 0.25 bpp. Bandelet compression, for Lena image has 0.16% better quality in PSNR, for satellite image 1 has 1.62% better quality in PSNR, for satellite image 2 has 3.46% better quality in PSNR, for satellite image 3 has 0.68% lower quality in PSNR, for satellite image 4 has 8.77% better quality in PSNR, for satellite image 5, has 1.53% better quality in PSNR.

Compare to CCSDS image data compression, JPEG2000 has higher compression quality for compressing at 0.25 bpp. JPEG2000 compression, for Lena image has 0.87% better quality in PSNR, for satellite image 1 has 2.79% better quality in PSNR, for satellite image 2 has 7.00% better quality in PSNR, for satellite image 3 has 0.05% better quality in PSNR, for satellite image 4 has 13.64% better quality in PSNR, for satellite image 5, has 1.97% better quality in PSNR.

JPEG 2000 has best performance compare to other three compression method, for 0.25 bpp. This show by biggest PSNR compares to others, but this is not valid for all bit rates of all test images. Comparison graphics of every images such as figure 8, 9, 10, 11, 12, and 13. Base from those figures we can see that JPEG has very good performance in high compression ratio or low bit rate. We also see that wavelet compression always has lower quality compare to Bandelet for most satellite images at all compression rate. Bandelet compression and CCSDS image data compression, Bandelet compression has better performance at low bit rate or higher compression ratio and CCSDS has better performance at high bit rate.

If we saw entropy of image, it has very low correlation with image quality, but for very big difference such as satellite image 1 and Lena or satellite image 2 and satellite image 1, we can see the relation is low entropy can give better performance. Compare to Lena image, satellite image has lower entropy. It can reach until 28.2% lower than Lena image such as satellite image 1. Satellite image 1 and 3 are medium resolution satellite images. Satellite image 2, 4, and 5 is a high resolution satellite image. For medium resolution satellite, image quality comparison between Bandelet and wavelet compression only has small difference quality even some image at 0.25 bpp wavelet better than Bandelet (for satellite image 1) and this is valid for all bit rate from the comparison Figure 9 and Figure 11, we can see the gap between wavelet compression line and Bandelet compression line is small. For high resolution satellite image, image quality comparison between Bandelet and wavelet comparison has bigger difference quality and even better for well-organized area such as satellite image 2 and 4. This differences we can be seen from Figure 10 and Figure 12, the gap between wavelet compression line and Bandelet compression line is big. This means that Bandelet has better performance for high satellite image especially for well-arranged area.

Lossless compression does not recognize image quality because for lossless reconstructed image has to be the same for every pixel. We can recognize better algorithm with higher compression ratio. From table 4 we can see that lossless JPEG 2000 has higher compression than lossless CCSDS image data compression. This mean JPEG 2000 has better performance compare to CCSDS image data compression. JPEG 2000 has better performance from 0.8% up to 6.3 % compare to CCSDS image compression. The compression ratio has low correlation with the entropy only for very big differences such as satellite image 1 which has much smaller entropy so it has biggest compression ratio. It means only if so much smaller entropy can be related to higher compression ratio.

4.2. Time consumption

Time consumption for compression and decompression is related to the complexity of the algorithm. Longer time means more complexity the algorithm and otherwise faster means lower complexity. Time comparison can only be used if the algorithm in the same software implementation because different software implementation can also make processing time different such as MATLAB implementation take longer time than C programming. Wavelet and Bandelet compression can be compare timely because both are implemented in MATLAB. JPEG2000 and CCSDS image data compression can be compare timely because both are implemented in C programming. It is hard to compare between other implementation but still can describe roughly.

Bandelet compression need more time about 3 to 4 times longer than wavelet compression for compressing, and 30% to 38% for decompressing. Bandelet compression is time costly, and it also show Bandelet is much more complexity. Before we use this calculation we have to consider how much quality we can achieve. For example, if we use for high resolution satellite image especially with well- arranged area, this algorithm can be effective. But if we use it for medium resolution satellite image, we should not use it because with only little quality gain it cost so much time.

JPEG 2000 compression needs more time up to 3 times compare to CCSDS image data compression for compressing, and up to 2 times for decompressing. This shows that CCSDS image data compression has much lower complexity than JPEG 2000 compression. This is related to the main constraint for satellite image for low complexity.

Entropy has no correlation to the processing time, lower entropy does not have to make processing time faster. CCSDS lossy compression has the lowest complexity compare to other compression algorithm, compare to Bandelet it can reach until 15 times faster.

Lossless image data compression using CCSDS and JPEG2000, as shown in table 4. CCSDS image data compression has faster compression and decompression time. This also shows that lossless CCSDS image data compression has lower complexity than JPEG 2000 compression. CCSDS image data compression has better time processing than JPEG 2000 but it has lower compression ratio. JPEG 2000 can have up to 6.8% higher compression ratio but cost 2 times longer processing time compare to CCSDS image data compression.

Lossy and lossless image compression from table 3 and table 4, we can see processing time between compression and decompression time. Processing time for most of algorithm decompression has faster compare to compression time. For wavelet compression the compression time and decompression time is the same (rounded to 1 decimal place). For Bandelet, compression time can reach up to 2 times longer than decompression time. For JPEG 2000 lossy compression, compression time up to 33% longer than decompression time. For JPEG 2000 lossless, compression time up to 63% longer than decompression time. For CCSDS lossy image data compression, compression time can reach up to 57% longer than decompression time. For CCSDS lossless image data compression, compression time up to 52% longer than decompression time.

5. Conclusion

All method used for satellite image compression with mainly using wavelet transform have been simulated in this research. Compare to wavelet compression, Bandelet compression has better performance for most all bit rate. Lossy JPEG 2000 compression has best performance in low bit rate, but the performance is not good for high bit rate. Bandelet compression has better performance at low bit rate or higher compression ratio and CCSDS has better performance at high bit rate. CCSDS image data compression has much lower complexity compare to Bandelet compression, it even lowest complexity compare to other tree method. Bandelet compression has better performance for high satellite image especially for well-arranged area. CCSDS image data compression has the fastest compression and decompression time, but Bandelet compression has better image quality compare to CCSDS image data compression. Bandelet compression is time costly, and it also show Bandelet is much more complexity. CCSDS has the fastest compression and decompression time compare to other methods. Lossless CCSDS image data compression has faster compression and decompression time compare to lossless JPEG 2000 compression. But JPEG 2000 has more compression ratio compare to CCSDS image data compression.

The use of Bandelet transform as an addition in CCSDS compression should be consider for next research, this combination can be good for satellite image in high resolution especially for well-arranged area, and will make improvement in lossy compression for high compression ratio such in JPEG 2000. A study to geometric approach to a satellite image such as Bandelet should have an algorithm for lossless compression to achieved higher compression ratio in lossless compression.

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