REPORT ON THE PERFORMANCE OF THE PROPOSED STANDARD FOR LOSSY MULTISPECTRAL AND HYPERSPECTRAL DATA COMPRESSION

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Abstract

This report analyzes the coding performance of the proposed standard for lossy multispectral and hyperspectral data compression, focusing on the choice of spectral transform.

The following conclusions, in terms of SNR, were observed:

- Among the tested wavelet transforms, the lossless CDF 5/3 provides the best results both in lossy and lossless, by a very slight margin.
- Isorange POT provides similar performance as the (original) isonorm POT.
- Almost always the POT outperforms wavelets. For the general case, a KLT applied as an ALT outperforms the other transforms.

Table of Contents

Glossary of acronyms

bpppb bits per pixel per band

DWT Discrete Wavelet Transform

IWT Integer Wavelet Transform

KLT Karhunen-Loève Transform

PAE Peak Absolute Error

POT Pairwise Orthogonal Transform

IPOT Integer Pairwise Orthogonal Transform

SNR Signal-to-Noise Ratio

9/7M IWT CDF 9/7M

9/7 DWT CDF 9/7

5/3 IWT CDF 5/3

IRPOT Iso Range Integer Pairwise Orthogonal Transform

ALT Arbitrary Linear Transform

1 Outline

The purpose of this document is to compare the coding efficiency of various spectral transforms in order to identify which are the best candidates for transform based candidate standard.

This document is composed of three sections:

- A comparison of wavelet transforms to identify the best performing one.
- A comparison of POT variations to determine if the isorange POT is acceptable.
- A comparison of the best wavelet, the best POT, and the KLT as a ALT.

2 Methodology

For each of the tested transforms, a comprehensive evaluation has been performed over all the images of the recommended corpus (annex A), at bitrates from 0.25 to 4.5 in increments of 0.25 bpppb. Results are provided for SNR Energy, and PAE; however, the rate allocation employed minimized MSE with no constraint of PAE.

Each individual experiment was performed three times, each with a different rate-allocation method: full-frame lagrange, strip lagrange, and reverse-waterfill. In addition, results contain various upshift and down-shift amounts (from 0 to 5 bits, and 8 bits).

Wavelet transforms where applied with 5 levels. The POT used a $\Omega = 13$, $F = 1$, *stable flip mode*, and side information in *compressed* format. The ALT results were calculated as a KLT in full-frame mode (i.e. $F_0 = 2^{16}$), which may not be suitable for images with more that a few bands.

As a reference results for the ALT are provided for most images, except for those where they would take excessive computation time (> 50 minutes per compression and decompression).

The complete results of these tests can be found in an external zip file.

3 Performance of wavelet transforms

In this section we compare the performance of wavelet transforms, these are the 5/3, the 9/7 and the 9/7M. The efficiency of each wavelet is analyzed for lossy and lossless applications.

3.1 Wavelet Lossless Performance

For the lossless case only the 9/7M and 5/3 wavelets are considered in combination with a 2D Integer Wavelet Transform (IWT).

Looking at the experimental results of the 5/3 and 9/7M, we note that in most cases the 5/3 slightly outperforms the 9/7M in terms of SNR. Discrepancies where the 9/7M provides better results than the 5/3 are mainly isolated to images containing a limited number of bands (2-10).

In terms of PAE, the 5/3 transform produces slightly better results compared to the 9/7M.

3.2 Wavelet Lossy Performance

For the lossy case the 9/7, 9/7M and 5/3 wavelets are considered in combination with a 2D Discrete Wavelet Transform (DWT).

Looking at the experimental results it can be noted that the 5/3 and the 9/7 transform both slightly outperform the 9/7M except for the images composed of a limited amount of bands. In general the 5/3 performs similarly better than the 9/7 and but more regularity across bitrates.

These results are particularly notable with local rate optimisation algorithms (Local Lagrangian, Reverse Waterfill) while the use of a Global rate allocation algorithm provides less decisive results between the 9/7 and the 5/3. While the 5/3 does not systematically outperform the 9/7 it does so at a lower computational cost and with less dynamic range expansion.

In terms of PAE the 5/3 produces slightly more stable results than other transforms.

⇒ **Since there is no significant difference, the 5/3 is selected because of implementation considerations (it is faster and it is isorange).**

4 Performance of POT variations

In this section we compare the performance of POT variations, these are the POT (lossy transform), IPOT (integer transform) and IRPOT (integer isorange transform). The efficiency of each wavelet is analyzed for lossy and lossless applications.

4.1 Lossless Performance of POT variations

For the lossless case the IPOT and IRPOT are considered in combination with a 2D IWT.

The results between the two transforms are notably similar in terms of SNR and PAE independently of the optimization algorithm used. The IRPOT offers a little more stability across bitrates for fixed (upshit-downshift) level (5-4, 5-5). In a few cases the IRPOT outperforms the IPOT significantly (see MODIS image). The IRPOT performs worse than the IPOT with a zero upshift.

4.2 Lossy Performance of POT variations

For the lossy case the POT, IPOT and IRPOT are considered in combination with a 2D DWT.

For the SNR metric results it can be seen that all three transforms perform very similarly, independently of the rate optimization algorithm. However, the IRPOT tends to offer slightly more stability across bitrates for a fixed (upshift-downshift).

⇒ **Similarly, since there is no significant difference, the IRPOT is selected because of implementation considerations (it is isorange).**

5 Overall Performance

In this section all the following transforms are compared for performance, the the 5/3, the IRPOT, and a KLT as an ALT.

5.1 Overall Lossless Performance

In the lossless use case all the aforementioned transforms were combined with a 2D IWT.

The results clearly indicate better results for IRPOT in comparison to the 5/3 both in term of SNR and PAE.

5.2 Overall Lossy Performance

In the lossy use case all the aforementioned transforms were combined with a 2D DWT.

The results clearly indicate, in term of SNR, better results for KLT in comparison with the other two transforms, except for a few images where the IRPOT either matches or outperforms the KLT. There are a few cases of non-uniformity-corrected images where the 5/3 performs slightly better than the IRPOT. In terms of PAE results are varied depending on the image, with the IRPOT being the best for most of them, followed by the KLT and then the 5/3 wavelet.

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Annex A: Experimental Setup Details

A.1: Images and bit rates

The experiments are performed over the corpus of images selected by the CCSDS-MHDC working group to provide results for lossy compression of multi- or hyperspectral images (Table 1). Target bitrates are, as per the group requirements, 0.1, 0.25, 0.5, 1.0, 2.0, and 4.0 bpppb.

Table 1: Corpus details

Name	Type	Bands	Height	Width	Bitdepth
AIRS-Granule-9		1501	135	90	unsigned / 13
AVIRIS-Hawaii-raw	raw	224	512	614	unsigned / 10
AVIRIS-Yellowstone-Sc00-rad	rad	224	512	677	13 +signbit / 14
AVIRIS-Yellowstone-Sc00-raw	raw	224	512	680	unsigned / 15
CASI-t0477f06-raw-nuc	nuc	72	1225	406	unsigned / 13
CASI-t0477f06-rad-rss	rad	72	1225	406	unsigned / 15
CASI-t0477f06-raw	raw	72	1225	406	unsigned / 12
CRISM-frt00009326_07_sc167-nuc	nuc	545	510	640	unsigned / 13
CRISM-frt00009326_07_sc167-raw	raw	545	510	640	unsigned / 12
CRISM-frt00009326_07_sc167ir-nuc	nuc	438	510	640	unsigned / 13
CRISM-frt00009326_07_sc167ir-raw	raw	438	510	640	unsigned / 12
CRISM-frt00009326_07_sc167vnir-nuc	nuc	107	510	640	unsigned / 11
CRISM-frt00009326_07_sc167vnir-raw	raw	107	510	640	unsigned / 11
CRISM-hrl0000648f_07_sc182-nuc	nuc	545	450	320	unsigned / 13
CRISM-hrl0000648f_07_sc182-raw	raw	545	450	320	unsigned / 12
CRISM-msp00004125_05_sc214-nuc	nuc	74	2700	64	unsigned / 11
CRISM-msp00004125_05_sc214-raw	raw	74	2700	64	unsigned / 11
Hyperion-GeoSample-nuc	nuc	242	1024	256	unsigned / 12
Hyperion-GeoSample-raw	raw	242	1024	256	unsigned / 12
Hyperion-GeoSample-FlatFielded	raw + ff	242	1024	256	12 +signbit / 13
IASI-Desert		8461	60	66	unsigned / 12
Landsat-Agriculture		6	1024	1024	unsigned / 8
Landsat-Coast		6	1024	1024	unsigned / 8
Landsat-Mountain		6	1024	1024	unsigned / 8
M3-globalA-nuc	nuc	86	512	320	unsigned / 11
M3-globalA-raw	raw	86	512	320	unsigned / 12
M3-targetB-nuc	nuc	260	512	640	unsigned / 12
M3-targetB-raw	raw	260	512	640	unsigned / 12
MODIS-MOD01.A2001222.1200_250m-nuc	nuc	2	8120	5416	unsigned / 12
MODIS-MOD01.A2001222.1200_250m-raw	raw	2	8120	5416	unsigned / 12
MODIS-MOD01.A2001222.1200_500m-nuc	nuc	5	4060	2708	unsigned / 13
MODIS-MOD01.A2001222.1200_500m-raw	raw	5	4060	2708	unsigned / 12
MODIS-MOD01.A2001222.1200day-nuc	nuc	14	2030	1354	unsigned / 13
MODIS-MOD01.A2001222.1200_day-raw	raw	14	2030	1354	unsigned / 12
MODIS-MOD01.A2001222.1200night-nuc	nuc	17	2030	1354	unsigned / 13
MODIS-MOD01.A2001222.1200_night-raw	raw	17	2030	1354	unsigned / 12
MSG-RC15		11	3712	3712	unsigned / 10
Pleiades-Montpellier-T		4	2456	224	unsigned / 12
Pleiades-Montpellier-T-Misregistered-020		4	2448	296	unsigned / 12
Pleiades-Montpellier-T-Misregistered-035		4	2448	296	unsigned / 12
Pleiades-Montpellier-T-Misregistered-050		4	2448	296	unsigned / 12
SFSI_mantar-nuc	nuc	240	140	496	unsigned / 9
SFSI-Mantar-rad-rmnoise	rad + rn	240	140	452	15 +signbit / 16
SFSI-Mantar-raw	raw	240	140	496	unsigned / 11
SPOT5-Toulouse-1		3	1024	1024	unsigned / 8
VEGETATION-1-1b		4	10080	1728	unsigned / 10
VEGETATION-1-1c		4	10080	1728	unsigned / 10