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Original
Onboard Data Reduction for Multispectral and Hyperspectral Images via Cloud Screening / Cilia, Martina; Prette, Nicola; Magli, Enrico; Sang, Bernhard; Pieraccini, Stefano. - ELETTRONICO. - (2020), pp. 6230-6233. (Intervento presentato al convegno IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium tenutosi a Hawaii, USA nel 26 Sept.-2 Oct. 2020) [10.1109/IGARSS39084.2020.9323641].

Publisher:
IEEE

Published
DOI:10.1109/IGARSS39084.2020.9323641

ONBOARD DATA REDUCTION FOR MULTISPECTRAL AND HYPERSPECTRAL IMAGES VIA CLOUD SCREENING

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ABSTRACT

In this paper we propose a lossless and lossy onboard compression algorithm for multispectral and hyperspectral images, based on the recent CCSDS-123.0-B-2 standard, which takes advantage of cloud screening in order to perform data volume reduction, by avoiding to transmit pixels that are covered by clouds. In particular, we develop methods addressing two problems: i) how to signal the cloud mask in the compressed file, and ii) how to handle cloudy pixels in order to maximize the amount of compression. Experimental results on a set of LANDSAT 8 ETM+ and AVIRIS images show a significant data volume reduction with respect to the plain use of the CCSDS-123.0-B-2 standard.

***Index Terms*—** onboard image compression, cloud screening

1. INTRODUCTION

Lossless and lossy image compression are by now routinely used on satellites and aircraft to reduce the volume of data to be transmitted to the ground. This can conveniently be done using compression standards developed for space applications, see e.g. [1]. The very large data rate generated by modern optical sensors is very problematic in terms of downloading the acquired data to the ground, often requiring to shorten the instrument duty cycle in order to acquire less images, or to employ lossy compression with a larger amount of compression in order to make room for more images. However, it is very often the case that the acquired images have a very large cloud cover percentage, so that a large fraction of the available downlink capacity is wasted to transmit information that bears little or no significance for Earth observation. This has been observed in [2], which proposed to exploit this aspect in order to increase data reduction by running a cloud screening algorithm onboard. The image is divided into blocks of lines, and for each block a cloud cover percentage is computed from the cloud screening results; if the cloud cover percentage of a block exceeds a given threshold, the block is simply not transmitted to the ground. Signaling is also very simple, involving a binary flag for every block, whereas the cloud mask is not needed at the decoder.

In this paper we propose an image compression method based on the recent CCSDS-123.0-B-2 standard for near-lossless compression of multispectral and hyperspectral images [3, 4]. The method can take advantage of any cloud screening technique that generates a spatial cloud mask. Differently from [2], we do not discard complete image blocks even if they are only partly covered by clouds; instead, we retain all the information related to the non-cloudy pixels in order to maximize scientific return. The interaction between the cloud screening method and the compression engine requires to develop techniques to adapt the compression process to this specific problem, and to embed the cloud mask in the compressed file as the mask is needed by the decoder. We devise and compare several techniques to address these problems, and apply them to LANDSAT 8 ETM+ images and AVIRIS raw images. The experimental results show that the proposed techniques achieve a significant data volume reduction, while maximizing the preservation of useful information in the images.

2. PROPOSED METHODS

In the CCSDS-123.0-B-2 standard, compression is based on a DPCM quantizer prediction loop. A spatial/spectral predictor outputs an estimate of the value of the current pixel to be encoded, as a function of a few decoded (past) neighboring pixels in the same spectral channel and in a few previous spectral channels. Then the corresponding prediction residual is quantized, and the sequence of quantized residuals is entropy-coded.

We assume that the output of the cloud-screening algorithm is a *cloud mask* where each pixel is represented as a binary value indicating whether or not the pixel is cloudy, or as an integer value that specifies the type of cloud. Based on the cloud mask, the compression stage may avoid encoding cloudy pixels.

In this scenario, if a part of the image is discarded (e.g. a cloudy pixel), some information is needed at the decoder, in order to understand the pixels coding order. In addition, it is desirable to keep the entire coding and decoding process compliant with the CCSDS-123.0-B-2 standard, otherwise a standard-compliant decoder might not be able to decode the image correctly.The abovementioned constraints are the major drivers for the design of the algorithms described in this paper. In the envisioned solution, we replace the cloudy pixels with a dummy value, and we send the cloud mask as ancillary information to the decoder, in order to reconstruct the original image. This raises two design problems. The first is related to the syntax for signaling the cloud mask to the decoder as ancillary information. The second is related to properly choose dummy values for the cloudy pixels, so as to maximize compression efficiency.

2.1. Cloud mask transmission

The CCSDS-123.0-B-2 standard allows the user to insert, in the header of the compressed image, up to 15 user-defined supplementary information tables. For each table, the user can define the table dimensions as well as the type of information included. For our purpose, the cloud mask can be signaled using one supplementary information table. The mask is encoded in the header as a sequence of unsigned integers on D bits, with $D = 1$ for a binary mask; we refer to this first method as "table insertion". This solution is perfectly compliant with the standard; however, the cloud mask is encoded in uncompressed format, even if a spatial correlation is obviously present.

The spatial correlation of the cloud mask can be exploited considering values of the cloud mask as if they were pixels of the image, i.e. the mask can be inserted in the image as an additional fictitious band, and it can be encoded using the compression algorithm. This second solution is referred to as "band insertion". We encode the cloud mask separately from the rest of the image and in a lossless way, whereas all other image bands are encoded following the usual compression process.

2.2. Pixel replacement

We replace each cloudy pixel with a dummy value; such dummy values should be very easily compressible in order to enhance the prediction and reduce the residual, leading to a reduction of the data volume. We consider two different ways of choosing them.

The first method is referred to as "pixel replenishment"; it replaces cloudy pixels and then applies compression to the obtained image. We define as (y, x, z) the coordinate of the pixel in the original image (column x, row y and band z), and (y', x', z') the coordinate of the pixel in the replenished image. A cloudy pixel is replaced by an average A over neighboring pixels. At the image boundary, only the available pixels are used to calculate the average as $A = 0.25[(y' - 1, x' - 1, z') + (y' - 1, x', z') + (y' - 1, x' + 1, z') + (y', x' - 1, z')]$.

We have also considered a second method. Instead of explicitly choosing a dummy value, we force the residuals to be equal to zero for cloudy pixels; this is equivalent to choosing as dummy value the prediction generated for the cloudy pixel from its neighboring pixels during the compression process. The coding block of the compressor will encode the residuals of each pixel using an adaptive Golomb encoder: if the residual is zero, then the encoded bit length is expected to be the shortest possible one. This solution cannot be performed as a preprocessing stage, because it requires to override the calculation of the residuals for cloudy pixels, and these residuals are not known in advance. Due to the availability of the cloud map, the encoder is also perfectly synchronized with the decoder. Thus, this modification does not affect the ability of the decoder to properly perform the decoding process. Hereinafter, we refer to this solution as "zero residual".

3. EXPERIMENTAL RESULTS

3.1. Dataset and experiment setup

We have tested our proposed solutions on a dataset of Landsat 8 ETM+ images [5] containing cloudy images along with their cloud masks [6]. From the dataset we have extracted 13 images having different cloud cover percentages, which have been used as our experimental test set. We note that these are not raw images; however, we argue that these results are still representative, since the application to raw images would simply increase the obtained bit-rate for all images by a very similar amount; we do provide results on raw AVIRIS images in Sec. 3.3. Moreover, in some cases it can be envisaged to generate the images directly onboard, so that compression could be applied to the generated images [7].

We have combined the different approaches for cloud mask transmission and pixel replacement, comparing four different settings: i) Pixel replenishment with table insertion (PT); ii) Pixel replenishment with band insertion (PB); iii) Zero residual with table insertion (ZT); iv) Zero residual with band insertion (ZB). Compression has been run using the full predictor in wide and neighbor oriented mode, 3 previous bands for prediction, sample representative parameters all set to 0, and sample-adaptive entropy coder.

3.2. Results

We perform the experiments using different values of the quantization step Δ, ranging from 0 (lossless compression) to 32. The bit-rate after the compression stage of the image is reported in Tab. 1. Specifically, we numerically compare our proposed methods with the value obtained using the original CCSDS-123.0-B-2 standard, referred in the table as ”123”. Since the results are comparable for images with the same percentage of cloudy pixels, the table shows only three examples, considering that the other images in the dataset behave accordingly. The cloud cover percentage is equal to 15, 51 and 65 % for the three images respectively.

The results in Tab.1 show that in most cases we are able to reduce the amount of transmitted data, while being able to decode the useful information with the intended quality. If the percentage of cloudy pixels is below 25%, the two approaches utilizing the ”table insertion” method may not improve the performance because of the overhead due to the longer header. This issue can be easily avoided by triggering the replenishment only if the cloud cover exceeds a given percentage. Moreover, it is minimized for hyperspectral images, since the overhead due to the cloud mask for PT and ZT is spread over a large number of spectral bands. On the other hand, ”band insertion” always outperforms ”table insertion” and provides a compression benefit compression.

Table 1. Bit-rate comparison among proposed methods (bpppb) for three sample LANDSAT images.

	Δ	**123**	**PT**	**PB**	**ZT**	**ZB**	**[2]**
1	0	8.83	9.05	8.77	8.99	8.72	8.88
	2	6.52	6.74	6.46	6.68	6.41	6.57
	8	4.80	5.03	4.75	4.97	4.70	4.85
	32	3.15	3.38	3.11	3.34	3.06	3.19
2	0	8.20	5.98	5.68	5.74	5.45	4.30
	2	5.88	4.35	4.06	4.23	3.93	3.10
	8	4.15	3.25	2.95	3.17	2.87	2.21
	32	2.48	2.26	1.96	2.23	1.93	1.34
3	0	8.33	5.67	5.39	5.38	5.10	2.13
	2	6.02	4.17	3.88	4.02	3.74	1.57
	8	4.35	3.18	2.90	3.10	2.81	1.16
	32	2.80	2.32	2.04	2.28	2.00	1.68

For what concerns the comparison between PR and ZR, their performance is similar, with the latter providing a slight improvement with respect to the former. The gain becomes larger as the percentage of cloudy pixels increases, and as the quantization step becomes smaller. We note that, while it seems obvious that setting the residual to zero should minimize the residual and hence the bit-rate, the ZR method may cause the statistics of the residual to depart from Laplacian, which is the assumption under which the sample-adaptive Golomb coder employed in the CCSDS-123.0-B-2 standard is close to optimal. Finally, the method in [2] achieves higher reduction especially for large cloud cover percentage, but it also preserves much less information.

In Tab. 2 we summarize the results obtained over the complete image test set considering the average data rate reduction (bpppb) of ZT and ZB on images grouped by cloud cover percentage. The gain is higher if the percentage of cloudy pixels is more than 50%. In the lossless case, the reduction is up to 3 bit per pixel, and reduces to about 0.7 bit per pixel for $\Delta = 32$. The ZB method always provides a gain. Indeed, keeping the compression engine compliant with CCSDS-123.0-B-2 incurs a price due to the signaling overhead.

3.3. Extension to hyperspectral images

We have also tested the proposed methods on hyperspectral images from AVIRIS. However, there is no available

Table 2. Average rate reduction over the test set.

% cloud	Δ	**ZT**	**ZB**
0−25%	0	0.17	0.46
	2	0.11	0.39
	8	0.03	0.32
	32	-0.15	0.20
26−50%	0	1.53	1.82
	2	1.15	1.44
	8	0.79	1.08
	32	0.34	0.62
51−76%	0	2.72	3.02
	2	1.86	2.15
	8	1.16	1.45
	32	0.41	0.70

cloudy dataset for these images; hence, we have created a small dataset from a real AVIRIS raw image employing a simple cloud pattern that is repeated throughout the image to obtain different cloud cover percentages. Tab. 3 summarizes the results on three images having cloud cover percentage equal to 3, 24 and 40 % respectively. Since the number of spectral bands is much higher than in the LANDSAT case, a non-negligible data volume reduction is obtained even when the percentage of cloudy pixels is small. Furthermore, it is possible to observe that the cloud mask overhead is negligible even if the mask itself is not compressed. Hence, the gain is essentially the same for all the methods and, in this case, the modification of the standard does not produce any significant benefits. Finally, we note that the method in b3 not only discards useful information but also degrades the performance for images with low cloud coverage.

4. CONCLUSION

We have proposed a method to perform data volume reduction for multispectral and hyperspectral images by employing cloud screening information, in the framework of the CCSDS-123.0-B-2 standard. We have proposed different solutions to embed the cloud mask in the compressed file, and to replace cloudy pixels with dummy values. The proposed techniques allow to obtain significant data volume reductions, as shown on LANDSAT 8 ETM+ and AVIRIS images, especially when the cloud cover percentage is large.

Table 3. Bit-rate comparison among proposed methods (bpppb) for three sample AVIRIS images.

	Δ	**123**	**PT**	**PB**	**ZT**	**ZB**	**[2]**
1	0	5.83	5.77	5.75	5.77	5.75	5.86
	2	3.55	3.49	3.47	3.49	3.47	3.58
	8	2.00	1.95	1.94	1.95	1.94	2.03
2	0	6.43	5.64	5.63	5.65	5.63	6.44
	2	4.14	3.37	3.36	3.36	3.35	4.15
	8	2.54	1.94	1.92	1.92	1.91	2.55
3	0	6.68	5.42	5.41	5.44	5.43	4.7
	2	4.39	3.17	3.16	3.16	3.15	3.05
	8	2.76	1.86	1.84	1.84	1.83	1.90

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