6th International Workshop on On-Board Payload Data Compression

OBPDC 2018

20 - 21 September 2018
Torre Spagnola, Matera (Italy)

Programme & Abstracts

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Detailed Programme OBPDC 2018

Thursday 20 September 2018

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Giovanni Sylos Labini
CEO of Planetek Italia

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National Research Council Of Italy

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NASA - Jet Propulsion Laboratory

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Universitat Autònoma de Barcelona

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Prof. Enrico Magli, Politecnico of Torino

Session 3: Applications (ESA and non-ESA Mission)

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Li Li
Dsi Aerospace Gmbh

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Universitat Autònoma de Barcelona

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15:50 Creative thinking on selected topics
Round table discussion on selected topics, to foster innovation and the spread of ideas

17:00 Wrap-up of the Workshop - Conclusion
Raffale Vitulli (ESA) – Roberto Camarero (CNES)

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Abstracts - Oral Presentations

Invited Speaker: Weapons of (EO) Value Chain Mass Distruption - How OBDH will change Earth Observation Value Chain

Sylos Labini G.
Planetek Italia

No abstract available.

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Session 1: On-board data selection/data reduction

Streak Detection for Space Debris observation: IN-SITU comes to an end.

Vives Vallduriola G[1], Biersack F[1], Suárez Trujillo D[1], Daens D[1], Scharf A[1], Helfers T[1], Utzmann J[2], Vananti A[3], Pittet J[3]
[1]*Airbus Defence And Space Gmbh,* [2]*Airbus Defence And Space Gmbh,* [3]*Astronomical Institute of the University of Bern (AIUB)*

Modern society depends heavily on satellite infrastructure. However, Space becomes more and more congested by space debris from over 50 years of space activities. This growing threat in orbit must be monitored. The aim of the ESA GSTP activity „Optical In-Situ Monitor“ is to design and test a breadboard of a space-based space debris camera and to develop and test its end-to-end processing chain.

The on-board processing functions will focus on the payload image processing in order to reduce the data volume (image segmentation for streak detection).

The suitable technologies for the processing units will be described: the HPDP, an ARM-Cortex R5F processor and Microsemi’s RTG4 FPGA. For image processing, several algorithms were tested extensively: the CCSDS 122.0-B-1, the Boundary Tensor and the Differences Method.

This paper shows the results of the project and gives an overview of which combination of processor-algorithm yields the most promising results for our mission.

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Introducing k3-raster Compact Data Structure for Hyperspectral Images

Chow K[1], Tzamarias D[1], Blanes I[1], Serra-Sagristà J[1]
[1]*Universitat Autònoma de Barcelona*

The idea of using compact data structures [1] to make data more densely packed has been around since it was first introduced in a paper written by Guy Jacobson in 1989 [2]. This representation provides for fast and direct data access without an initial decompression stage. The storage capacity is also being kept close to the information-theoretic minimum. Thus the reduced data size helps shorten the wait time while the data are being transferred through the communication channel. Algorithms such as FM-index and Burrows-Wheeler Transform are examples of compact data structures that have already found their use in genome sequencing, text-searching and data compression (bzip2) applications. Other future uses may include on-board data selection and reduction of already compressed payload data. However in this project, we will focus on some compact data structures that are suitable for remote sensing images and in particular hyperspectral images.

Experiments using compact data structures on 2D raster images have been performed in the past several years with encouraging results. A structure which is called k2-raster has been used in a particular line of research for raster images and it is the one that we base our research on. k2-raster can be described as a kind of k2-trees, which, in turn, are a kind of quadtrees. Their main advantage is that they offer the image the ability to be compactly represented. Details of the k2-raster structure and the experiments that were carried out can be found in the papers quoted below [3-5]. Since hyperspectral images used in this project are 3D datasets with a varying number of bands, we needed to modify and extend the k2-raster algorithms to also take in the z-coordinate that indicates the band in which the pixel is located. The resulting new structure is aptly called k3-raster. Its ability to read in 3D data as a whole chunk proves to be beneficial as it does not require the data to be broken down, such as when it is used with k2-raster.

The functions in k3-raster were modified from k2-raster functions. They include the construction of k3-raster data, the querying of a cell value, and the querying of the values in a range of cells. Using some images from the Landsat program as input data, we found that the k3-raster data file is comparable in size to a gzip file compressed from the original image. Both yielded a compression ratio of around 34%. For random cell queries done 1000 times, the time it took was 0.1 seconds. When done 100000 times, the results turned out to be similar.

In conclusion, all the experimental results have shown that k3-raster proves to be a viable compact data structure for hyperspectral images. In future work, we would also like to report more results from other programs such as AVIRIS and Hyperion, and to adapt our structure to distributed environments.

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Real-time cloud detection in high-resolution videos; challenges and solutions

Francis A.[1,2], **<u>Sidiropoulos P.[1,2]</u>**, Vazquez E.[1]
[1]Cortexica Ltd., [2]Mullard Space Science Lab, University College London

Motivated by a large number of applications that have been developed using high-resolution satellite imagery, the community has recently started exploring the acquisition of high-resolution video from satellite instruments. High-resolution satellite video would allow the development of tools for the real-time monitoring from space of road and airport traffic from space, natural phenomena such as fires and tsunami, etc. Furthermore, the temporal redundancy present in video streams could be used for generating products of better quality, finer resolution (e.g. using super-resolution) and even 3D products from a single orbit.

However, raw high-resolution satellite videos may reach up to several GBs even for a few seconds of videos, especially if a large frame per second (fps) rate is selected. Additionally, the straightforward option of increasing either the on-board data storage capabilities or the downlink speed is not supported by the current technology status. Instead, the acquisition and transmission of video data from space could become realistic through the use of on-board video compression algorithms which would significantly reduce the data volume that will be downlinked to the ground. While an initial compression can be achieved by using some video compression standard (e.g. H.264/AVC), the compression rate can be boosted by an information analysis pre-processing step which would guide an optimised content-aware satellite video compression method.

Content-aware satellite video compression is feasible due to the presence of common semantic features on satellite imagery, which are associated with a different level of information content. Perhaps the most common semantic feature with reduced information content (for surface monitoring applications) are clouds, especially thick clouds that totally obscure the surface. The real-time on-board detection of clouds would benefit greatly satellite video compression since such an algorithm could be incorporated in a compression pipeline that uses different compression rates on a single video, each based on the cloud coverage and thickness of the corresponding surface region. However, the real-time on-board cloud detection is far from being trivial, since it requires two conflicting requirements; high-quality performance that would accurately detect clouds if possible in the nominal resolution and fast speed that would follow the nominal video fps rate. Traditional cloud detection algorithms achieve exactly one of these goals at the expense of the other, thus becoming impractical for on-board applications.

On the other hand, the recent progress in artificial intelligence which is associated with the proliferation of deep learning technology has triggered the development of tools that achieve accurate semantic annotation of image content (including videos). Recently, the deep learning community has introduced fast and light architectures that don’t undermine severely the pipeline accuracy, thus being tailored for on-board data analysis. In this work, we present a pipeline under development that uses texture and colour information from high-resolution satellite videos in a deep learning architecture that additionally takes into account temporal redundancy in order to generate fast and accurate cloud detection products.

As a matter of fact, the development starts from a simple (but still useful) output, follows a progressive direction towards more ambitious and more informative cloud detection products. More specifically, the first pipeline, which will be presented and discussed in detail, process video frames in order to generate two outputs: a single number estimating the percentage of pixels which are obscured by clouds, and a binary bitmask with each value expressing whether the corresponding pixel is obscured by clouds or not. The algorithm is quantitatively validated in one image and one video dataset, the former originating from Landsat data and the later from the recent Carbonite-2 mission. Additionally, qualitative comparisons of our cloud detection algorithm with the one used to extract cloud masks in Sentinel 2 data are going to be presented, to further validate the accuracy gain achieved by the developed algorithm. Finally, computational time estimation is going to be given, in order to certify that the real-time cloud detection in high-resolution videos is not beneath the current state-of-the-art.

Acknowledgment: The research leading to these results has received partial funding from the UK Space Agency Centre for Earth Observation Instrumentation.

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SpaceOP3C Evolution: a Hyperspectral/ Multispectral On-Board Compressor Leveraging Adaptive Avoidance Mechanisms for Outliers

Abbattista C. [1], **Amoruso L.** [1], Fortunato V. [1], Iacobellis M. [1], Sykas D. [1]
[1]*Planetek Italia srl*

Planetek Italia already implemented in SpaceOP3C (On board payload Processing for Compression, Classification and Cloud detection) a new methodology for near lossless and lossy compression of Hyperspectral/ Ultraspectral/ Sounding sensors. We used a hybrid methodology, called HUNPCA (Hybrid UN-mixing PCA), which utilizes a customized spectral un-mixing procedure and PCA, combined with a lossless generic coding algorithm.
We further improved SpaceOP3C to account for: 1) adaptive detection of outliers and their handling in the compression process, 2) for leveraging spatial redundancy, 3) being resilient to wrong-registration of bands, 4) combining bands and tiling to improve PCA efficiency and, finally, 5) running on parallel architectures (because of specific algorithmic techniques employed). The spatial redundancy is exploited by creating an augmented synthetic input: this is done by selecting specific pixels from each source layer and by using them to build specific layers to create a new data cube (an "enrichment" process of the original cube along the depth dimension). This produces a positive effect on the PCA processing and improves overall compression performance indicators. We introduced a new step in the compression workflow for determining outliers and allow the user to choose a set of management policies. And as last improvement, special attention was devoted to refactorization of algorithmic steps and methodologies to make the compressor suitable for deployment on resource constrained embedded systems. Results show improved compression ratios versus acceptable data degradation, given a specific SNR value of the sensors/data. An adaptive operating mode selector was also introduced to best fit the compressor behavior to the input data structure (e.g. number of input bands).

The HUNPCA compression algorithm was designed by Dimitris Sykas (inventor) and an international patent (application number PCT/EP2015/070628) was filed on behalf of Planetek Hellas. Moreover, it was funded by the H2020 program “SME Instrument” and received the “Seal of Excellence” certificate. This methodology is demonstrated on two different sensors: AVIRIS (airborne) and Hyperion (spaceborne). We used the standard dataset provided by Aaron et al. 2009 in cooperation with NASA and the Consultative Committee for Space Data Systems (CCSDS) for hyperspectral compressor benchmarking. We accomplished the evaluation of the compression algorithm in terms of data loss by using the similarity metric: Spectral Angle Difference (SAD). SpaceOP3C's algorithm and engineering characteristics & performances are compared with the CCSDS 121.0, 122.0 and 123.0 compressors.

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GPU technologies for on-board data reduction. The debris detection use case

Abbattista C. [1], Amoruso L. [1], Fortunato V. [1], Iacobellis M. [1]
[1] *Planetek Italia srl*

The Satellite Missions scenario, from Earth Observation to Science, to planetary rovers, is enormously changing both for the number of the deployed assets and for the acquisition capability of the embarked sensors. The result is a considerably increased data volume to manage on-board and to download to ground stations.
The final goal of an EO Service Company like Planetek Italia is "to provide the needed information at the right time for its customers". To accomplish that we have define a new paradigm, called SpaceStream, where the separation between Data nodes, Processing nodes and Communication nodes is completely overcome to fulfil the Timeliness by improving Reactivity, Responsiveness and Latency.
The key technologies supporting the SpaceStream involve the full stack of the On Board Payload Data Processing (OBPDP), one of the core businesses of Planetek Italia, going over the simple tasks of compression, binning, checking and reduction.
It means that the processing capabilities of On Board Computers play a more and more important role in the satellite value chain. Among the high performance architectures available in the Ground Segment scenario, the GPU has been recognized as one of the most promising being it designed to apply repetitive computations to a large amount of data. In fact, a GPU is a SIMD (Single Instruction Multiple Data) vector machine and even the more complex algorithm contains computations to be applied to all the pixels of the image acquired by the sensors. Nevertheless the same GPUs can effectively work as MIMD (Multiple Instruction Multiple Data) machines.
In this paper we present and demonstrate the possibilities provided by the correct exploitation of GPU architectures for a space debris monitoring system and how to overcome the challenges relative introduced by the same usage of GPU.
The core of the system is the automatic processing technique able to autonomously detect objects of interest and estimate (or improve on those already known) their orbital parameters.
Data selection is performed by an algorithm for sources extraction allowing automatic detection of known objects and space debris in optical data. It is based on an algorithm able to distinguish both the kinds of feature present in the optical image (streaks and point-like objects) performing extraction using a single frame without the need of external ancillary data.
Currently GPU usage has not yet been adopted on-board, due to the specific constraints of the space environment and of space systems and we can only rely on similar processing boards for the embedded systems world. In our case the speedup and the efficiency of the proposed pipeline for sources extraction has been demonstrated both on a workstation and on an embedded Nvidia Jetson TK1 platform.

Session 2: Compression Algorithms

Multichannel SAR Onboard Data Reduction: Dynamic Block Quantization based on Principal Components

Guccione P[1], Giudici D[2]
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High resolution and wide swath (HRWS) imaging are conflicting but desirable requirements in the design of future spaceborne Synthetic Aperture Radar (SAR) systems. In fact, high azimuth resolution requires high Doppler bandwidth and so a high Pulse Repetition Frequency (PRF) to avoid aliasing; on the other hand, the swath width is related to the separation of pulses, i.e. a large swath width requires sufficient distance between consecutive pulses and so a low PRF. A way to overcome this limitation has been proposed in literature and consists of advanced instrument modes and architectures employing multiple receive channels in azimuth. According to the general version of the sampling theorem, it is possible to perform a coherent combination of each received signals to cancel out the ambiguous parts of the Doppler spectra, due to the use of a lower PRF. A lower PRF, on the other side, allows the design of a larger swath. The on-ground combination of the spectra during the data processing results in an equivalent system with a band that is n times higher than the one allowed by the reduced PRF. The different aperture may be implemented on a single platform (in this case the multichannel system is called Displaced Phase Center technique) or on different platform, leading to the multistatic SAR.

One of the main problem in multichannel/multistatic systems is the large amount of data generated by the instrument(s) during acquisition. The data volume, that linearly increases with the number of receiver, could be managed by solutions such as larger on-board storage and broadband downlink channels or by reducing the orbit duty cycle. However, all these solutions imply a cost increasing, which is opposite to the philosophy behind the New Space framework, where constellations of cheap Mini Satellites or CubeSat are envisaged.
Quantization of multichannel SAR has already attracted the attention of scientists and some papers have been published in the past, proposing a manipulation of data before quantization (example: Fourier transform).

In this work, we propose the use of a compression scheme that takes advantage of the high correlation among the different channels. The scheme performs a dynamic dimensionality reduction: in practice, Principal Component Analysis is applied to a number of azimuth lines and range samples (a block of data) taken from all the channels. Then, the number of component to retain is dynamically selected on the basis of the allowed level of increased distortion. Finally, the survived components are quantized using the Sentinel-1 onboard quantizer concept, the Flexible Dynamic Block Adaptive Quantizer (FDBAQ), in which the quantizer is selected among a finite number according to the input power at antenna. The idea is that if the input power is high, the quantizer should have a high number of levels to reduce the effect of quantization noise: in this case also the degradation due to reducing the number of components should be kept reasonably low. On the other hand, when the input power at antenna is low, quantizers with a low number of levels are selected since degradation due to thermal noise is prominent. In this case, the condition on the number of components can be relaxed (i.e. less component can be taken). The amount of compression clearly is a function of the level of correlation among channels and of the content of the scene (few point targets or distributed scatterers and level of backscattering coefficient).

Experimental results involving simulated dataset and reconditioned real acquisitions have been performed thanks to a proprietary SAR L0 data simulator.

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Some Results on the Use of Walsh Hadamard Transform for Image Compression

Soucaille J[1], Fraisse R[1], Mamdy B[1]
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The ever increasing capacity of new electronic components has open the way for more and more complex and sophisticated compression algorithms aiming to achieve the better image quality with the minimum allocation of bits per pixels in order to squeeze more and more data in a constrained downlink channel. This is the current paradigm.

With the apparition of the concept of constellation of a huge number of spacecraft, the unit cost per spacecraft begins to become a dominant factor and this is also true for the data handling unit of a remote sensing satellite. Furthermore, it is expected that new communication technologies (laser) will relax the constraints on data rates. For those reasons, it seems interesting to steer the design in the direction of a higher simplicity even at the expense of a slight degradation of quality or an increase regarding the data rate.
In the frame of this new paradigm the compression approach has been revisited with simplicity in mind. The proposed algorithm relies on a Haar operator in lieu of the traditional wavelet transform, an optimal Lloyd Max quantizer and a simple entropic coder. Simulations on typical satellite images show that the quality is on par with traditional algorithms above 3 bpp and that no structural artefacts are visible even at higher compression ratio.

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SHyLoC-e: improving CCSDS standard compliant IP cores for on-board lossless compression of hyperspectral images

Sánchez A[1], Barrios Y[1], Sarmiento R[1], Santos L[2]
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Hyperspectral imaging has multiple applications for identification, surveillance and navigation purposes. For that reason, the use of hyperspectral sensors in flight systems such as drones, planes and satellites is increasing. Hyperspectral sensors produce large amounts of data that have to be either processed or transmitted. Hyperspectral data processing requires a big computational capacity that is not usually available in on-board systems due to the limitations in terms of power consumption. On the other hand, the limited data transmission bandwidths with the ground stations in comparison with the size of hyperspectral images constitute a bottleneck in this kind of applications, which will be aggravated with the progressive increase in the resolution of hyperspectral sensors. Because of this, on-board compression of hyperspectral data becomes mandatory.

The Consultative Committee for Space Data Systems (CCSDS) has developed several lossless data compression standards specifically designed for space applications. These standards provide efficient compression together with a reduced complexity, which fits well with the limited computational resources available in space systems. Among these standards, the CCSDS-121 constitutes a universal compressor, while the CCSDS-123 specifically targets multispectral and hyperspectral images. Both compression standards make use of predictive pre-processing stages, well suited for low complexity implementations.

The European Space Agency (ESA) provides a portfolio of IP cores, which can be used by project partners for future space missions. This IP core portfolio has recently included two IP cores, which consist in hardware implementations of the CCSDS 121 and 123 compression standards respectively, which are known together as SHyLoC. These IP cores are provided as technology independent, configurable and synthesizable VHDL designs and they are capable of working separately as well as jointly. However, the SHyLoC IP cores do not implement the full functionality of the respective CCSDS standards. Namely, the CCSDS-121 IP does not implement the pre-processing stage defined in the CCSDS-121 standard, while the CCSDS-123 IP lacks the custom weight initialization option.

This work presents the modifications proposed over the SHyLoC IP cores in order to implement the full CCSDS standards, while at the same time achieving higher performance in terms of compression efficiency and throughput. On the one hand, the main feature of the extension of the CCSDS-121 IP is the inclusion of the unit-delay predictor defined in the standard, which additionally requires inserting reference samples in the compressed data. On the other hand, the extension of the CCSDS-123 IP includes the custom weight initialization. In addition, the throughput the CCSDS-123 IP can reach is improved in the Band-Interleaved (BI) architectures by optimizing the communications between the IP and the external memory where the intermediate residuals are stored, optimizing the use of the AHB bus. This project is supported by ESA through the TRP-AO8032 contract.

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Prepending Spectral Decorrelating Transforms to FAPEC: a Competitive High-Performance Approach for Remote Sensing Data Compression

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The Consultative Committee for Space Data Systems (CCSDS) has recently published the CCSDS 122.1-B-1 recommendation [1] defining a data compression algorithm for three-dimensional image data from payload instruments, including multispectral and hyperspectral imagers, and specifying the compressed file format.

The UAB GICI group has participated in the definition of this recommendation, which is an extension to CCSDS 122.0-B-2 [2] and which introduces several options for spectral decorrelation of three-dimensional data. It includes the identity transform, the integer wavelet transform (IWT), the pairwise orthogonal transform (POT) [3,4] and the arbitrary affine transform (AAT). While IWT and POT guarantee perfect reconstruction, AAT cannot always guarantee lossless compression.

On the other hand, the IEEC/ICCUB and DAPCOM have developed FAPEC [5], a high-performance data compressor which is already being used onboard some nanosatellites. FAPEC also offers hyperspectral image compression options, which provide high compression throughputs but typically lower ratios than those achieved by the CCSDS 122.1-B-1 recommendation.

In this work we test the combination of some spectral decorrelating transforms included in CCSDS 122.1-B-1 with the FAPEC entropy coding core. We evaluate the feasibility and interest of integrating these spectral transforms in such a high-performance compressor. We compare the results obtained with those achieved by the current FAPEC options available and with those from the CCSDS recommendation.

Lossless coding results are reported on several multispectral and hyperspectral scenes, including AIRS, AVIRIS and SPOT5. These reveal that FAPEC can benefit from incorporating some of these spectral transforms as a pre-processing stage, yielding compression ratios close to those of the CCSDS 122.1-B-1 recommendation at a high computing performance.

The spectral decorrelation and entropy coding systems are tested on a high-performance data handling platform being developed at the IEEC for cubesats, in order to evaluate the feasibility of high-end hyperspectral data handling in nanosatellites.

Future work will investigate the integration of the spectral decorrelating transforms with FAPEC for lossy compression.

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Influence of the System MTF on the Lossless Compression of Hyperspectral Raw Data

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In the framework of a project funded by Tuscany Region aimed at developing enabling technologies for the design of a compact low-weight imaging hyperspectral instrument, the influence of the MTF of the acquisition system on the performance of lossless compression algorithms of the raw data is investigated. Notwithstanding there are many constraints on MTF design, it has also been recognized relevant to quantify its impact on performances of data compression with the aim of reducing transmission bandwidth/power and on-board mass storage.

In this perspective, standard CCSDS data as Aviris 2006 hyperspectral scenes are considered and used for the experiments. In fact, these data are row and their spatial resolution is adequate for simulating the data that should be acquired by the sensors to be designed, whose resolution is foreseen at about 100m.
To this end, a series of simulated MTFs kernels are considered to filter the original AVIRIS data, followed by a suitable resampling to reach the final resolution. Successively, state-of-art lossless compression algorithms will be applied, in order to quantify the improvements in compression ratio due to the reduction of aliasing and the increment of correlation of the data.

MTF requirements are usually provided on the basis of the minimum value (cut-off) that this function must assume at the Nyquist frequency, defined as an half of the sampling frequency. A typical cut-off between 0.2 and 0.3 constitutes an important constraint for the acquisition system and usually ensures a good contrast in the acquired images. Diversely, a too high cut-off at the Nyquist frequency will produce aliasing distortion.
The MTFs considered to assess the compression performances are Gaussian-shaped kernels and exhibit an incremental cut-off in the range [0.1 - 0.5]. Plausible resolutions of the instrument in the range [60m – 150m] are also considered the simulations.

The analysis performed in this work is expected to provide useful information not only in the design of this instrument but for future missions in general.

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Performance Impact of Parameter Tuning on the Emerging CCSDS-123.0-B-2 Low-Complexity Lossless and Near-Lossless Multispectral and Hyperspectral Image Compression Standard

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The upcoming Issue 2 of the CCSDS 123.0-B standard for Low-Complexity Lossless and Near-Lossless Multispectral and Hyperspectral Image Compression supersedes the previous Issue 1 of the same standard, Lossless Multispectral & Hyperspectral Image Compression [1]. Issue 2 extends Issue 1, primarily by incorporating support for near-lossless compression, while retaining lossless compression capabilities (and all other features) of Issue 1.

The cornerstone behind Issue 2 of the standard is the newly available option for near-lossless compression provided by an in-loop quantizer embedded in the prediction stage of the compressor. In addition, Issue 2 incorporates several other features to improve the coding performance for near-lossless compression: prediction representatives, weight exponent offsets, narrow prediction modes, and a new hybrid entropy coder. A full description of the new standard is provided in the companion paper [2].

As with the previous Issue 1, several tunable parameters are available to implementers and end users. Employing different settings for these parameters may allow an implementer to achieve different trade-offs between implementation complexity and compression efficiency, or may allow an end user to fine tune compression performance for particular data sets. This paper studies these parameters and provides guidelines on how to adjust them to achieve high coding efficiency for a representative corpus of multi- and hyperspectral images. The current study includes revisiting our previous assessment of parameter settings under lossless compression [3] while considering the newly available coding options, in addition to providing new guidelines for both old and new coding options for near-lossless compression.

The new hybrid entropy coder is available as the second of the two stages of a CCSDS 123.0-B compressor, to encode the output of the first (prediction) stage. This entropy encoder is designed to provide good performance under a wide range of coding options, and, as such, a reasonable set of guidelines under which to adjust this stage are obtained first. Settings related to the prediction stage are evaluated afterwards, and in combination with an already adjusted entropy encoder, with the idea of attaining a reasonable set of combinations of coding options to examine.

Experimental results include data from 12 different instruments representative of varied detector types, image dimensions, number of spectral bands, bit depth, levels of noise, level of calibration and other image characteristics.

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Compression of Hyperspectral Images with Graph Wavelets

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Hyperspectral images are data structures that depict sceneries across many bands of the electromagnetic spectrum, often used in order to find objects, identify materials, or forecast the weather. These images usually contain large amounts of data and require the use of efficient compression techniques. A recent approach to this subject is the use of graph signal processing, a technique where data are represented as signals lying on the nodes of graphs [1], while graph edges denote similarities between nodes. By exploiting the information provided by graph edges, data compression methods using techniques such as biorthogonal graph wavelets [2] produce competitive results. Our research, although still in its early stages, might provide useful on-board data compression applications.

The method proposed in [3] compresses hyperspectral images by iteratively processing groups of consecutive bands. For each group the authors apply a graph bior transform on two different graphs. The first application of the transform is along the group of bands (on the so-called spectral graph) and is followed by a transform on each individual band (spatial graph). To avoid encoding the graph structure, the spatial graph is shared among all bands of the same group and is constructed from the luminance values of the last band of the previous group.

In this paper we conduct a study on how the construction of the spectral and spatial graphs affects the compression of hyperspectral images based on the method proposed in [3]. One of our studies relates to the proposition in [2] where the authors state that it is advantageous to create an edgemap in order to locate and disconnect nodes that correspond to non smooth transitions of the image which may otherwise prove expensive to encode. Following the above proposition, image segmentation through k-means [4] and normalized cuts [5] are used to explore if appropriately disconnected spatial graphs improve coding performance. The creation of a spatial graph using all bands of the previous group is also examined. Functions such as the ‘and’ operation are tested, which disconnects two nodes if it is suggested by at least one band. Finally different graph structures are tested that are k-regular with different sizes of neighborhoods k. Along this experiment we also study the effect of combining the euclidean distance with the luminance difference of pixels in a Gaussian kernel, in order to compute the weights between nodes. Experimental results are provided comparing the performance of the proposed techniques for several hyperspectral scenes available at the CCSDS website [6].

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Session 3: Applications (ESA and non-ESA Mission)

Deep Learning: a Great Fit for Onboard Data Processing?

Prof. Enrico Magli , Politecnico of Torino (invited speaker)

This talk will review deep learning from the basics up to some recent developments, with an eye on the applicability to onboard data analysis. It will cover convolutional networks, recurrent networks and generative adversarial networks, and review some recent results in the fields of satellite data and image analysis, and particularly satellite image segmentation and prediction of geomagnetic events for space weather applications. Finally, the talk will discuss the opportunities and challenges of deploying deep neural networks for onboard payload data processing.

Bio: Enrico Magli is a Full Professor at Politecnico di Torino, where he leads a research group active in the field of image and video coding and analysis, compressed sensing and security. He is an Associate Editor of the IEEE Transactions on Circuits and Systems for Video Technology, and the EURASIP Journal on Image and Video Processing, and a former Associate Editor of the IEEE Transactions on Multimedia. He is a Fellow of the IEEE and has been an IEEE Distinguished Lecturer for 2015-2016. He is a co-recipient of the IEEE Geoscience and Remote Sensing Society 2011 Transactions Prize Paper Award. He has been general chair of IEEE ICME 2015 and IEEE MMSP 2013, and TPC chair / area chair for several conferences. He has published over 250 scientific papers and filed 8 patents. He is a co-founder and President of the ToothPic start-up

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EO-ALERT: Next Generation Satellite Processing Chain for Rapid Civil Alerts

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Earth observation (EO) data delivered by remote sensing satellites provide a basic service to society, with great benefits to the civilian. The data is nowadays ubiquitously used throughout society for a range of diverse applications, such as environment and resource monitoring, emergency management and civilian security.

Over the past 50 years, the EO data chain that has been mastered involves acquisition process of sensor data on-board the satellite, its compression and storage on-board, and its transfer to ground by a variety of communication means, for later processing on ground and the generation of the downstream EO image products.

While the market is growing, the classical EO data chain generates a severe bottleneck problem, given the very large amount of EO raw data generated on-board the satellite that must be transferred to ground, slowing down the EO product availability, increasing latency, and hampering applications to grow in accordance with the increased User Demand for EO products.

This paper provides an overview of the EO-ALERT project, an H2020 European Union research activity that addresses the challenge of a “high speed data chain” and the need for increased EO data chain throughput. EO-ALERT proposes the definition and development of the next-generation EO data and processing chain, based on a novel flight segment architecture that moves optimised key EO data processing elements from the ground segment to on-board the satellite. The objective is to deliver the EO products to the end user with very low latency for increased throughput.

Achieving this goal poses great challenges on the flight system, to be addressed through a combination of innovations in the on-board elements of the data chain and the communications link. As such, this goal necessitates innovation in several critical technological areas; namely on-board reconfigurable data handling, on-board image generation, on-board image processing, high-speed on-board avionics, on-board data compression and reconfigurable high data rate communication links to ground. Such innovations will also provide capabilities for the optimisation of the classical EO data chain towards a data chain with greatly improved data throughput.

The paper will present preliminary project results on the above technological areas, with particular attention to the development of a flexible and reconfigurable data handling architecture integrating different on-board technologies for both SAR and optical sensor data, including image generation, image processing for rapid alerts, joint compression and encryption algorithms. The paper will also discuss possible applications of the envisioned high-speed data chain and introduce open issues regarding the implementation of the proposed architecture, from the use of dedicated hardware platforms to COTS-based implementations. The aim is to raise interest in this ambitious project from the on-board data compression and processing community, share their views on the different technological challenges, and foster fruitful discussions towards new ideas and solutions.

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Improving Performance of CCSDS122.0 Image Data Compression on Microsemi RTAX FPGAs

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This paper shows our recent work on improving performance of CCSDS122.0 Image Data Compression on Microsemi RTAX FPGAs. A previous implementation on a single RTAX2000 FPGAs has been successfully integrated into Data Handling Assembly Unit of German EnMAP project and Data Handling Unit of Proba-V project. The throughput reaches 173Mbps @ 66Mhz working clock frequency. The data rate becomes a bottleneck when integrated together with nowadays standard payload mass memory module, where the achievable data rate is usually higher than 1Gbps.

We extended our architecture by using two RTAX2000 FPGAs: The first FPGA performs Discrete Wavelet Transform (DWT) and the second FPGA performs Bit Plane Encoder (BPE). The image data is firstly stored into local SDRAM memory so that the support of larger image lines becomes possible. Double buffering mechanism is implemented so that stalling by iterative DWT is prevented.

The image is then divided into image tiles of size 512 by 512, on which DWT is performed. One level 2D-DWT is implemented by three filters and 16 line buffers in FPGA. The coefficients of sub-bands HHx, HLx, LHx and LL3 are directly forwarded to BPE FPGA. The LL1 and LL2 are written back to SDRAM buffer for next level transformation. With a running clock frequency of 66Mhz, the DWT reaches the throughput of 80Mpixels per second (equivalently 960Mbps@12-bit pixel data or 1120Mbps@14-bit pixel data).

The transformed image tiles are firstly stored into local SDRAM of BPE FPGA. Quad buffering mechanism (on image tiles) is implemented in order to balance the performance gap in case the BPE becomes faster (at high compression factor). The bit plane encoding is performed segment by segment. Two BPE engines can be implemented in a single RTAX2000 FPGA, which runs at 66Mhz. For lossless compression, two BPEs reach the data rate of 2*280Mbps=560Mbps (average compression factor of 2). For lossy compression, if only 50% bit planes are encoded (estimated compression factor of 3.5), the data rata is doubled to 1120Mbps, which matches the data rate of DWT FPGA.

The optimized compression FPGA architecture enables us to integrate CCSDS122.0 compression function into modern payload data handing units, not only as offline compression module but also as online compression module. When compared to single RTAX2000 FPGA solution, the data rate throughput of lossless compression is increased by a factor of 3. Detailed memory organization, SDRAM band-width allocation, scheduling policy, performance gain analysis as well as resource consumption will be reported in full paper.

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CCSDS 123.0-B-1 Multispectral & Hyperspectral Image Compression Implementation on a Next-Generation Space-Grade SRAM FPGA

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The explosive growth of data volume from next generation high-resolution and high-speed hyperspectral remote sensing systems will compete with the limited on-board storage resources and bandwidth available for the transmission of data to ground stations making hyperspectral image compression a mission critical and challenging on-board payload data processing task. The image compression algorithms used on-board must be designed with respect to certain performance-complexity tradeoffs inherent in space data systems design. The CCSDS has issued CCSDS 123.0-B-1 as the recommended standard for Lossless Multispectral and Hyperspectral image compression. The recommended standard uses an adaptive filtering method, achieving a combination of low complexity and compression effectiveness, able to provide state-of-the-art coding performance. Apart from the constraints on compression algorithm design, space data systems design imposes strict requirements on the on-board data processing hardware platform, which must provide a) radiation hardness/tolerance, b) high data-rate performance for Gigabit-rate applications and c) on-orbit adaptability. The Xilinx 65nm Virtex-5QV SRAM FPGA, currently in use in several commercial and military satellites, offers RHBD, high density and dynamic partial reconfiguration. Although the Virtex-5QV is a mature product in stable production accumulating heritage since 2014, recently, Xilinx announced the next generation of radiation tolerant space-grade FPGA technology, the 20nm Kintex Ultrascale XQRKU060 SRAM FPGA. Having performed well in SEE testing and with no identified need for additional RHBD modifications, the 20nm Kintex UltraScale technology is expected to reach space market availability in late 2019.

Existing hardware implementations of CCSDS 123.0-B-1 (or NASA FL) for space-grade FPGAs have been presented achieving up to 140 MSamples/s when implemented on a Virtex-5 FX130 FPGA and configured with BIP sample ordering.

In this paper, we propose a novel, high data-rate performance hardware accelerator, implementing the CCSDS 123.0-B-1 algorithm as an IP core targeting reprogrammable space-grade FPGAs. The top level architecture of the CCSDS 123.0-B-1E IP core compression engine consists of a Spectral Slice Buffer (SSB), a Predictor and an Encoder. The introduced architecture uses C-slow retiming, to exploit inherent task-level parallelism in the CCSDS 123.0-B-1 algorithm under BIP sample ordering and implements a reconfigurable fine-grained pipeline in critical feed-back loops, achieving very high throughput performance. The pipeline budget available, which depends on the minimum number of spectral bands, is optimally distributed on both predictor and encoder loops, using a novel RTL design pattern based on compile-time generics and a microarchitecture exploration driven approach based on synthesis and implementation experimental results. The SSB provides the sample neighborhood to the predictor using an optimized Block RAM FIFO and elastic buffer cascade organization. The CCSDS 123.0-B-1E IP core is a single FPGA solution with without external memory requirements that allows significant savings in SWaP-C (Size, Weight, Power and Cost). The CCSDS 123.0-B-1E IP core provides standard FIFO (i.e. AXI4-Stream) interface for data I/O and a memory-mapped register bank (AXI4-Lite or APB) for configuration, control and status providing flexibility in integration. It is configurable at compile-time using VHDL generic constants and at run-time using the configuration registers. At system level, the data I/O and configuration registers can be easily accessed by industry standard high-speed serial link interfaces (e.g. SpaceFibre with RMAP target support).

The CCSDS 123.0-B-1E IP core has been extensively verified in behavioral simulation with unit and integration testing against a software implementation of the compression standard (ESA SW implementation in C), using a significant amount of test images and configurations, including images from the CCSDS corpus of Hyperspectral and Multispectral tests. The IP core was also validated on-chip using a Xilinx development board as a hardware demonstrator with a Virtex-5 FPGA (XC5VLX110T-1) interfacing over PCIe, using a purpose built integration wrapper.

The CCSDS 123.0-B-1E IP core achieves maximum data-rate at ~312 MSamples/s (5 Gbps @ 16-bits per sample) when targeting the next-generation space-grade 20nm Kintex Ultrascale (XCKU060-1 COTS equivalent) FPGA using 2.55% of LUTs and 7.45% of BRAMs for a typical hyperspectral image configuration (AVIRIS instrument). When targeting the mature 65nm space-grade FPGA technology (Virtex-5 FX130-1 COTS equivalent), it achieves ~213 MSamples/s (3.3 Gbps @ 16-bits per sample) using 11% of LUTs and 27% of BRAMs. To the best of our knowledge, it is the fastest implementation of CCSDS 123.0-B-1 targeting a space-grade reconfigurable SRAM FPGAs to date.

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Lossless Data Compression Concept of the Destiny+ Dust Analyzer (DDA) Instrument

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The Destiny+ mission is part of JAXA's asteroid explore program. It addresses high-priority science goals for asteroid exploration, including key questions about the origin of our solar system. The destination of the spacecraft is the active asteroid (3200) Pheathon, whose characteristics, origin and processes are widely unknown.

The Destiny+ Dust Analyzer (DDA) is developed at IRS as the major measurement device of the Destiny+ spacecraft. The objective of the cosmic dust telescope is to analyze speed, dynamic, mass and composition of (3200) Pheathon during a flyby maneuver. Additional interstellar dust measurements are planned during the cruise phase. Due to the fact that the data downlink rates are very limited in this mission, a very efficient and reliable lossless data compression method is needed.

The recommended lossless compression coding technique for space missions by CCSDS is the Rice algorithm, defined in the standard 121.0-B-2-Lossless Data Compression. The corresponding CCSDS lossless Data compression greenbook 120.0-G-3 gives a short overview about possible applications (images and Spectrometer data). Because these examples do not fully fit to the DDA requirements (f. e. small amount of data and the possibility to compress using larger block sizes), we started to investigate for more suitable coding techniques.

After a broad literature research, we compared some compression techniques with the Rice algorithm. Because of the similarity of the instruments, the Cassini dust analyzer (CDA) of the Cassini Huygens mission serves as data base. The analyzed coding techniques are:

- linear prediction with possible stereo coding
- vector quantization with residual coding
- different vector formation methods
- 7z (LZMA, BZip, PPMd)
- DPCM
- arithmetic coding

As a result, we can show that coding methods with a large functional overhead are not suitable for deep space missions, due to already very small original data size. Furthermore, we can demonstrate the advantages of classic compression algorithms LZMA and PPMd in combination with larger block sizes over the recommended Rice algorithm in the context of the DDA project. This leads to the idea to upgrade the CCSDS standard 121.0-B-2-Lossless Data Compression to take deep space mission like Destiny+ into consideration.

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An Analysis of Optical Compressive Imaging Concepts for Space Applications

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The increasing amount of data generated by space applications poses several challenges due to limited resources available onboard: power, memory, computation, datarate.

In this paper, we propose Compressed Sensing (CS) as a key tool to face these challenges via compressive imaging. This signal processing technique, only recently applied to space applications, dramatically simplifies the image acquisition featuring native compression/encryption and enabling onboard image analysis. In practice, CS represents a signal (or image) through a small set of linear measurements, i.e. $y=Ax$, where x is the image of interest, A is a sensing matrix, and y is a vector of measurements having much fewer entries than x. Since A is typically chosen as a random matrix with independent and identically distributed entries (i.i.d.), y is also called a vector of random projections.

In order to investigate the potential benefits of CS in a realistic space application scenario, we first reviewed compressive imaging techniques and already existing prototypes and concepts, critically discussing the technological issues involved. The most critical components in the design of a CS-based system, especially when dealing with space qualification, are the Spatial Light Modulator, the electronic or electro-mechanical component performing the random projections, and the detector, which physically performs the integration in the transform domain.

Then, we proposed a set of instrument concepts in the application domains of space science, planetary exploration and earth observation, most suitable for a CS-based application. Each concept was evaluated in terms of relevant technological readiness, modulation methods and strategies, but also addressing mass and power budgets, and number and/or types of components needed. Compression efficiency (in terms of Compression Ratio, Signal-to-Noise Ratio, processing time) was also preliminarily assessed on the basis of available data that were acquired by similar traditional instruments. The set includes:

- A Hyperspectral imager with tunable filter or dispersive elements on rover for Planetary Exploration, working in the spectral range of UV-SWIR.
- A Camera on Orbiter for Space Science, working in the spectral range of EUV.
- A Hyperspectral imager with dispersive elements on orbiter for Space Science, working in the spectral range of UV-VIS.
- A THz Single-pixel imaging with a Si wafer based optical modulator, and a IR single-pixel imaging device with a DMD based modulator, for Space Science, working in the ranges of THz and IR, respectively.
- A Camera for sky observation and real-time detection of Near Earth Objects working in the MIR-TIR spectral range.

Among these, two most promising concepts were selected: the Hyperspectral imager with dispersive elements on orbiter for Space Science and the Camera for sky observation and real-time detection of Near Earth Objects. The Camera operating in the MIR-TIR has to be regarded as a value-added instrument for dual-use operation: it is actually capable of exploiting the potentiality of CS for the retrieval of the information without reconstructing the scene, yet maintaining the possibility of reconstructing the entire image at ground. Some hardware components for this instrument, however, are not commercially available, yet, making the choice of this instrument less recommended, even if with a high potential. On the contrary, the UV-VIS hyperspectral imager with dispersive elements adopts a more conservative approach and all the technologies needed for its construction are commercially available. For this reason, we go deeper into the analysis showing preliminary reconstruction performance tests of the UV-VIS hyperspectral imager.

Preliminary reconstruction results were obtained using simulated image of a star field of size 512x512 with a sparsity degree of approximately 0.001. The image was simulated depicting three star spectra from the STIS (https://archive.stsci.edu/prepds/stisngsl/) spectral library, and recalculating the intensity level according to the envisaged system parameters (optical transmittance, integration time, etc.). The acquisition of the image includes also the presence of photonic noise, whose model slightly differs from the "standard" CS model considering the presence of AWGN, only. The reconstruction from CS measurements was performed using a greedy algorithm, namely, the Orthogonal Matching Pursuit, with an overestimated sparsity degree of approximately twice the real sparsity degree of the image. The results showed that for a compression ratio of 1/10 the relative error on significant components is about 0.3%, with satisfactory reconstruction of the interesting portions of the image, i.e. those containing the star spectra.

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The New CCSDS Standard for Low-Complexity Lossless and Near-Lossless Multispectral and Hyperspectral Image Compression

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In 2012, Issue 1 of the CCSDS-123.0-B standard for lossless compression of multispectral and hyperspectral images was published [1]. This standard has been very successful and has already been adopted by several missions.

Because of the significant data volume reduction often needed to meet spacecraft downlink limitations, lossy compression is becoming increasingly used in space applications. With this motivation, the CCSDS

Multispectral and Hyperspectral Data Compression working group has been developing Issue 2 of this compression standard, extending the standard's capabilities to provide low-complexity near-lossless compression while still supporting lossless compression. This paper describes Issue 2, focusing on its new features and capabilities.

The most significant new feature Issue 2 is the incorporation of an in-loop scalar quantizer in the compressor's prediction stage to provide near-lossless compression. Quantizer step size can be controlled via an absolute error limit, so that samples can be reconstructed with a user-specified bound on reconstruction error, and/or a relative error limit, so that samples predicted to have smaller magnitude can be reconstructed with lower error. Quantizer fidelity settings can vary from band to band and can be updated periodically within the image. This flexibility could allow a user to adaptively adjust quantization parameters to meet a data rate constraint.

The predictor cannot in general utilize the exact values of the original data samples because these values will not be available to the decompressor at the time of reconstruction when compression is lossy. Instead, prediction calculations are performed using a sample representative in place of each original sample value. For some images, the obvious choice of setting the sample representative equal to the center of the quantization bin for the sample does not give the best compression performance; user-specified parameters that control the calculation of sample representatives allow a user to exploit this fact to improve compression performance in some cases.

Issue 2 introduces an optional simplification to the prediction calculation for the first frame of an image. This simplification eliminates a data dependency, thus facilitating a throughput improvement for some hardware implementations, though generally with a small reduction in compression effectiveness.

A new entropy coding option provides better compression of low-entropy data, which become increasingly prevalent as quantization step size increases. This hybrid entropy coder uses variable-to-variable length codes for low-entropy data, combined with the same Golomb-power-of-two codes used by the sample-adaptive coder for high-entropy data.

The compressed image syntax is extended to support the inclusion of optional supplementary information tables, which can provide ancillary image or instrument information to the end user, e.g., to identify malfunctioning elements in a detector array.

Moreover, Issue 2 supports high-dynamic-range instruments, allowing up to 32-bit signed and unsigned integer samples.

All features available in Issue 1 have been retained and the compressed image header structure of Issue 2 has been designed to ensure backwards compatibility with Issue 1. Thus, compressed images produced by a compressor that is compliant with Issue 1 will also be compliant with Issue 2.

Note that features added in Issue 2 are not limited to lossy compression capabilities. Thus, e.g., a losslessly compressed image that is compliant with Issue 2 might not be decompressible with a decompressor that is compliant with Issue 1. On that note, results show that even when compression is lossless, the use of the new entropy coder and sample representative calculation can sometimes provide improved compression performance over Issue 1.

Besides describing the general structure of this standard, the paper also presents some sample compression results. While these results are intended to highlight the main available features, the companion paper [2] provides an in-depth analysis of parameter selection to optimize performance.

References
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Session 4: High Performance Compression Implementation

High Performance Space Data Acquisition, Clouds Screening and Data Compression with modified COTS Embedded System-on-Chip Instrument Avionics for Space-based Next Generation Imaging Spectrometers (NGIS)

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Hybrid system-on-chip (SoC) devices that embed one of the world's most energy efficient processors (ARM Cortex-A9) and the latest and most powerful FPGA architecture (Xilinx 7-series) into a single chip (Xilinx Zynq Z7045Q) promise new opportunities due to the performance, power consumption, weight and volume benefits they bring. Currently, in spacecraft subsystems programmable logic and processors are usually combined as separate components, sometimes distributed across several circuit boards. NASA and other space agencies are considering SoC technology for future space missions due to its high computation capabilities and power efficiency. Despite the fact that currently there are no space-qualified SoC parts, NASA is testing commercial Xilinx Zynq SoC devices on the International Space Station (ISS) as well as in CubeSats operating in low Earth orbit (LEO), where the exposure to radiation is limited.

JPL and Alpha Data have developed SoC instrument avionics that performs data acquisition, cloud-screening and real-time compression for space qualified hyperspectral imagers. The system is implemented on the Xilinx Zynq-based modified 7Z1 COTS Alpha Data hardware assembly which fits into a 120mm by 190mm by 40mm assembly and has a peak power consumption of 9 watts. The computing element is a Xilinx Zynq Z7045Q. The 7Z1 COTS board was modified with PET Class 3 parts for LEO orbit suitability by eliminating unused functionality (Ethernet, USB, microcontroller), screening parts for destructive latch-up and populating with a rad-hard oscillator and a rad-hard watchdog timer/hardware reset. In addition to mitigate single event upset (SEU), error detection and correction code (EDAC) are implemented to scrub the FPGA configuration memory using the internal Xilinx Soft Error Mitigation (SEM) controller core and to boot safely the processor using multiple images stored in the on-board non-volatile memory to be used as fallback.

The SoC instrument avionics have been integrated with a NGIS-based implementation. Hyperspectral images are acquired, screened for atmospheric clouds, and compressed (either losslessly or lossily) in real-time using JPL's "Fast Lossless Extended" (FLEX) compressor, implemented in the programmable logic (PL) of the Zynq SoC device, and sent through Camera Link to ground support equipment (GSE), or through LVDS protocol to the spacecraft (S/C). In addition, the PL interfaces with the focus step motor, 32 temperature sensors, 12 heaters and an IMU/GPS device providing inertial/position information and time synchronization with S/C time. The processing system (PS) of the Zynq SoC implements command and data handling (C&DH) to program the hyperspectral camera (frame rate, exposure time), acquires telemetry (temperature, pulse-per-seconds counts, frames count), and controls heaters, a focus motor and the data flow inside the PL. The PS interfaces with the S/C command and telemetry (Cmd&Tlm).

The FLEX data compression algorithm exploits dependencies in all three dimensions of hyperspectral data sets, which produces substantially more effective compression than two-dimensional approaches such as applying conventional image compression to each spectral band independently. FLEX is a predictive technique that uses an adaptive filtering method to achieve a state-of-the-art combination of low complexity and high compression effectiveness, making it well-suited for hardware implementation. FLEX is the basis for the emerging Consultative Committee for Space Data Systems (CCSDS) CCSDS-123.0-B-2 standard for low-complexity lossless and near-lossless multispectral and hyperspectral image compression. Three FLEX IP cores have been integrated into the SoC Programmable Logic to provide a compression data rate of 70 frames/sec.

The SoC software architecture has multiple layers. At the bottom of the stack is the hardware component with custom SoC board, external memory and a custom carrier that connects the SoC board to the camera, the motor, the heaters, the compressed data, and the Cmd&Tlm. One layer up is the SoC FPGA fabric and custom logic. The interface to the hardware is abstracted using a C++ object-based abstraction layer. This provides functions for configuring the FPGA, reading and writing to the FPGA fabric, and handling interrupts. At the top of the stack is the NGIS application (API) which allows the S/C to interface with C&DH. In addition, the NGIS API has some diagnostic routines, such as checking that the memory banks in the FPGA design are working. The NGIS API communicates data, control and status with the flight computer, handles space craft inputs, and stores data to the local file system during ground tests.

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Feasibility Study of Implementation Aspects of Context Mixing Algorithms for FPGA based On-Board Payload Data Compression Systems

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Over recent years, volume and bandwidth of captured payload data by on-board instruments have increased explosively. These trends present a challenge for on-board data compression to minimize data volume and downlink budget.

The arrival of powerful embedded computing technologies provides the opportunity to use computationally intensive data compression techniques on board the spacecraft.

The goal of this paper is to evaluate the potential and implementation aspects of context mixing for FPGA based on-board payload data compression. Context mixing data compression algorithms are used in PAQ series of data compression archivers those prove themselves with high lossless compression ratio, but suffer from slow performance on single-core systems.

In this paper study of optimized context mixing algorithms for implementation in FPGA is proposed. This evaluation highlights potential challenges of implementation focusing on amount of necessary FPGA hardware resources, data flow aspects, throughput and memory resources. Thus ensuring the insight in future steps for development of high performance context mixing based on-board data compression systems.

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Parallel lossless Compression for Multispectral and Hyperspectral Images on Multicore and GPU architectures

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Parallel processing of data-intensive problems such as compression of multispectral and hyperspectral images on board satellites has stimulated considerable interest from both research communities and space agencies. Remote sensing devices generate increasing volumes of data, as the sensor technology evolves, which needs to be compressed before being transmitted to ground stations because the power and bandwidth used for transmitting images are scarce resources.

This study analyzed the level of performance gain that could be achieved through parallelization for the lossless compression algorithm described in the CCSDS 123.0-B-1 standard as well as how well the performance obtained scales up with the number of cores used. Along with compression ratio, the level of data and task parallelism that exists within compression algorithms could contribute to taking decisions on choosing compression algorithms in future space missions.

The parallelized implementation of the lossless compression algorithm has been evaluated on x86 (Linux), on two multicore embedded boards: GR-CPCI-Leon4-N2X (on top of a space ready operating system - RTEMS SMP) and NXP QorIQ P4080 (running Linux), as well as on a GPU (Graphics Processing Unit) for embedded systems applications from NVDIA.

The performance of the parallel implementation was evaluated with respect to the sequential implementation for solving the same problem. The parallelization scheme, for both prediction and encoding stages, of the compression algorithm is presented with a focus on how the computational effort was distributed evenly across the available processing cores and how synchronization between different stages of the algorithm was achieved.

Both sample adaptive and block adaptive entropy coders have been parallelized and their performance was compared and analyzed along with the impact of choosing the BSQ or BI format for storing the encoded code words in the output stream. Another criteria used for comparing the results obtained through parallelization was the impact of the image category, image size, and the number of spectral bands, on the performance of the implementation.

The proposed parallelized implementation was validated using datasets of calibrated and uncalibrated images from several instruments such as: Airs, Aviris, Casi, Crism, Hyperion, Landsat, M3, Modis, MSG, Pleiades, and SPOT5.

Results show that significant performance gain is obtained for both prediction and encoding stages of the compression algorithm, when using the parallel implementation. The weighted overall speedup of the parallel implementation (calculated for 95 images from CCSDS 123.1-Y-1) is 2.9 for quad-core x86 i5, 3.71 for quad-core Leon4, 3.5 (using 4 cores) and 6.07 (using 8 cores) on an octa-core P4080.

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Validation Method for Image Compressor Implementation

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Image compression algorithms for Earth observation satellites represent a complex validation challenge, from validation of the quantized version of the algorithm model, to validation of final Hardware RTL implementation. All these activities are particularly time consuming, with simulation runtimes increasing when going through the development cycle, for finally reaching the bottleneck of RTL simulations, which can last several days each. When performed sequentially, all these validation steps can represent more than 50% of the full compressor development time.

This paper presents an Image compressor validation method, shared by Image Quality Engineering teams and Hardware Engineering teams, which takes benefit of new RTL simulation accelerators. Such accelerators are based on Hardware Emulation and shorten RTL simulation run-times. These strongly reduced run-times allow important development advantages: time gain by parallelization of the different validation stages such as RTL versus Quantized C-model and Quantized C-model versus full precision algorithm model; flexibility, as late algorithm adaptation are then possible; anticipation, as effort can be put early on precise Image quality analysis: deep learning of quantized compression parameters influence and early identification of precise compressor configuration to be used during the observation mission.

This paper presents successful application of the validation method on a CCSDS-based algorithm for quality-controlled compression on Earth observation missions, in the frame of a CNES contract. It will remind the global validation strategy and present the main results in term of Image Quality and RTL development. The presented validation method can be used on future complex processing developments, including Hardware-Software systems.

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Hyperspectral Image Lossy Compression on a Reconfigurable and Fault-Tolerant Architecture Implemented over a COTS FPGA-based SoC

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The use of hyperspectral sensors on-board the satellites is considered essential for environmental studies. Current space missions are incorporating this kind of sensors and there is a tendency to include them in missions to analyse cosmic bodies, such as the Moon surface or Mars, mainly with identification and detection purposes. The acquired images from these sensors are big in terms of memory occupation and it is difficult to send them directly to the ground stations due to bandwidth limitations. Therefore, it is necessary to apply compression techniques on-board the satellites before sending them to the Earth surface, in order to reduce their volume.

In the other hand, Field Programmable Gate Arrays (FPGAs) have been used more and more for space applications due to their reprogrammable capabilities, good performance, low power consumption and cost reduction compare to ASICs. Although there are available in the market Rad-Hard By Design (RHBD) FPGAs specifically designed for space missions, at present the use of Commercial Off-The-Shelf (COTS) SRAM-based FPGAs is becoming interesting due to their greater performance in comparison with RHBD devices. Usually these FPGAs are combined with microprocessors in the same die, forming heterogeneous System-on-Chip (SoC) that increases the capabilities of the system in terms of computational operation without compromising its power consumption. However, this technology is vulnerable to radiation in space environments, which can cause errors in the configuration memory deriving in an incorrect operation of the system or even in its total failure. Nevertheless, a number of techniques, such as scrubbing and redundancy, are currently available to prevent or mitigate the radiation effects in order to preserve the data integrity and system functionality.

Regarding FPGA design, it is usually tackled at Register Transfer Level (RTL) but with the increase of the system complexity is necessary to use a methodology that allows to reduce both the design process and the Time-To-Market (TTM). In this way, a High-Level Synthesis methodology (HLS) approach can be used, starting from an algorithmic model in C/C++ language that is automatically transform by HLS tools in its equivalent RTL description.

This work presents an implementation of a lossy extension of the CCSDS (Consultative Committee for Space Data Systems) 123.0-B-1 lossless standard, specifically thought for multispectral and hyperspectral images. This standard is intended for space applications, looking for a trade-off between its compression efficiency and the design complexity. The proposed lossy extension includes a bit rate control to define the losses the compressor must introduce in order to achieve higher compression ratios without compromising the relevant image information. To complete the design flow, an HLS methodology has been followed. This system is implemented over a reconfigurable and fault-tolerant architecture, named ARTICo3, developed by the Universidad Politécnica de Madrid (UPM) and specially thought for space applications, including scrubbing and redundant techniques, such as Double and Triple Modular Redundancy (DMR and TMR, respectively), in critical parts of the FPGA fabric. The proposed solution is able to adapt the system operation taking into account different features, such as the computational performance, the power consumption or the robustness against faults. The reconfiguration engine runs on an ARM with embedded Linux OS. The system has been tested on both a Xilinx Zynq XC7Z020 and a Zynq UltraScale+ XCZU9EG, obtaining different results in terms of speed up depending on the number of hardware accelerators implemented on the ARTICo3 architecture. The results of this work have been obtained in a European funded project called ENABLE-S3, where ULPGC and UPM are partners in the aerospace use case.