Data Reduction and Compression Session
Data Reduction and Compression Session

Introduction to CCSDS compression standards and implementations offered by ESA

**Speakers:** Lucana Santos Falcon (ESA), Roberto Camarero (ESA)

Using CCSDS image compression standard for SAR raw data compression in the H2020 EO-ALERT Project

**Speaker:** Enrico Magli (Politecnico di Torino)

Preliminary On-board Image Processing Solution for the H2020 EO-ALERT Project

**Speakers:** Mr Juan Ignacio Bravo (Deimos Space), Dr Murray Kerr (Deimos Space)

Image dequantization for hyperspectral lossy compression with convolutional neural networks

**Speaker:** Dr Diego Valsesia (Politecnico di Torino)

Solar Wind Analyzer - The Solar Orbiter milestone Towards On-board Intelligent decision making systems

**Speaker:** Dr Vito Fortunato (Planetek Italia s.r.l.)

From a hyperspectral/ multispectral on-board compressor to a Knowledge-based on-board processor: spaceOP3C HW/SW evolution

**Speakers:** Dr Leonardo Amoruso (Planetek Italia s.r.l.), Dr Michele Iacobellis (Planetek Italia s.r.l.)

On-Board Data Reduction Software in CHEOPS

**Speaker:** Dr Roland Ottensamer (University of Vienna)
Introduction to CCSDS compression standards and implementations offered by ESA

Lucana Santos
Roberto Camarero
Introduction

1st complex on-board image processing ever?

→ Compression

↑ Duty cycle ↑

↑ Resolution ↑

↑ Dynamic Range ↑

↑ Throughput ↑

↑ Downlink ↓

Compressed image

Downlink

Decompression

Sensed image

EO mission

On-board compression

Compressed image

↑ Downlink capacity ↑
Introduction

How is compression possible?

- Redundancy
- Non-Redundancy
- Relevance
- Non-Relevance

Reject

Machine Learning

Quantization
Introduction

The challenge

Meet unique requirements of space missions and provide state-of-the-art performance

The goal

- Ease interoperability and adoption of compression
- Develop low-complexity high-throughput algorithms
- Ease efficient implementation on space-qualified HW
CCSDS compression standards

CCSDS algorithms (Consultative Committee for Space Data Systems)

- **CCSDS 122**
  - Lossless or lossy 2D compressor based on DWT

- **CCSDS 122.1**
  - Lossless or lossy 3D (1D+2D) compressor

- **CCSDS 121**
  - 1D Universal lossless based on Rice codes

- **CCSDS 123**
  - Multi/hyperspectral 3D predictive compressor
CCSDS compression standards

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CCSDS 123
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Image Data Compression: Lossy & Lossless

- DWT + Bit-Plane Encoder
- Progressive lossy to lossless
- Fixed-rate or fixed quality
- Green Book CCSDS 120.1-G-2
CCSDS compression standards

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Spectral Pre-processing Transform For Multispectral & Hyperspectral Image Compression: Lossy & Lossless

- Spectral transform (1D) + 2D compressor (CCSDS 122.0-B)
- Blue Book. Issue 1. September 2017

- 3 possible spectral transforms:
  - 1D Wavelet transform (5/3 “lossless” DWT)
  - ALT (Exogenous KLT): Pre-trained Fixed Arbitrary Linear Transform
  - POT
CCSDS compression standards

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CCSDS 123
- Multi/hyperspectral 3D predictive compressor
Lossless Data Compression

- Lossless low-complexity predictive compressor
- Green Book CCSDS 120.0-G-3
- Different options for different distributions
- Low-Entropy options

CCSDS 121.0
CCSDS algorithms (Consultative Committee for Space Data Systems)

- **CCSDS 122**: Lossless or lossy 2D compressor based on DWT
  - **CCSDS 122.1**: Lossless or lossy 3D (1D+2D) compressor
  - **CCSDS 121**: 1D Universal lossless based on Rice codes
  - **CCSDS 123**: Multi/hyperspectral compressor based on prediction.
Lossless Multispectral & Hyperspectral Image Compression

- Lossless low-complexity predictive compressor
- Based on Fast-Lossless (FL) algorithm (NASA)
  » Sample adaptive encoder (FL) & Block-adaptive encoder (CCSDS 121.0-B)
- 3D predictor adaptively adjusts prediction weights
- Green Book CCSDS 120.2-G-1
CCSDS compression standards

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CCSDS 122
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CCSDS 121
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CCSDS 123
- Multi/hyperspectral 3D predictive compressor
Low-Complexity Near-Lossless Multispectral & Hyperspectral Image Compression

- Beyond lossless: + quantization + new entropy coder for low entropy
- **Accurate quality control in pixel-by-pixel basis**
  - Bounded maximum and/or relative error
- Very low memory & computational resources (wrt CCSDS 122.1-B)
- Includes more efficient entropy coder for low bitrates

**Diagram:**
- Input image
- Prediction residual
- Spatial/spectral predictor
- Locally reconstructed image
- Sample Adaptive Entropy coder
- Block Adaptive (CCSDS-121)
- Hybrid encoder
- Encoder
- Compressed image
- Mapped quantified residuals
- Local decoder

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### Pros and Cons of each standard

<table>
<thead>
<tr>
<th></th>
<th>Type of Data</th>
<th>Complexity</th>
<th>Throughput</th>
<th>Lossless efficiency</th>
<th>Lossy efficiency</th>
<th>Fixed-rate Quality</th>
<th>Commercial counterpart</th>
<th>Relevant Space Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CCSDS 121.0-B-2</strong></td>
<td>1D 32 bits</td>
<td>😊😊😊😊</td>
<td>😊😊😊😊</td>
<td>😊😊😊😊</td>
<td>--</td>
<td>Variable-rate Lossless</td>
<td>JPEG-LS</td>
<td>SHyLoC ESA IP</td>
</tr>
<tr>
<td><strong>CCSDS 122.0-B-2</strong></td>
<td>2D 16 bits(B-1) 32 bits(B-2)</td>
<td>😞</td>
<td>😊😊</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Variable-rate Coarse quality control</td>
<td>JPEG2000</td>
<td>CWICOM ASIC</td>
</tr>
<tr>
<td><strong>CCSDS 122.1-B-1</strong></td>
<td>3D 16 bits</td>
<td>😞/😊*</td>
<td>😊</td>
<td>😊😊</td>
<td>😊😊</td>
<td>Variable-rate Mechanism for rate allocation</td>
<td>JPEG2000</td>
<td>--</td>
</tr>
<tr>
<td><strong>CCSDS 123.0-B-1</strong></td>
<td>2D/3D 16 bits</td>
<td>😊😊</td>
<td>😊😊*</td>
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<td>--</td>
</tr>
</tbody>
</table>

* Mode-dependent
Implementations supported by ESA

Key features

Lossless or lossy mode
Exact Fixed bit-rate
Equalization (non-uniformity correction)
CCSDS Source Packet formatting
**No Eternal Memory.** CQFP 256 ASIC
Bit accurate C reference software model

Budgets

60 Mpixels/s
Up to 16 bits
Max width up to **3496 columns**
Max height unlimited (push-broom)
Compression **0.5 bpp to 10 bpp**
Power ~100 mW/Mpix/s max (**5-6W max**)
SHyLoC Compression IP Cores

- Implementation of **two lossless compression IP cores**.
- **Described** in VHDL.
- Compliant with:
  - **CCSDS 121**
  - **CCSDS 123 lossless**
- Includes all configuration modes.
- Part of **ESA’s IP core’s Repository**.
- Developed by University of Las Palmas de Gran Canaria.
- Technology independent:
  - One-time programmable FPGAs (Microsemi);
  - Reconfigurable FPGAs (Virtex5);
  - ASIC (DARE libraries)
SHyLoC IP Cores

- The IP cores can be combined into a logical single entity.

- **CCSDS 123 IP core:**
  - High-performance lossless compression of multispectral and hyperspectral data.
  - Supports BSQ, BIP and BIL sample order.
  - Can be used as external pre-processor (predictor) for the CCSDS 121 IP core.

- **CCSDS 121 IP core:**
  - Universal lossless compressor based on Rice’s coding.
  - Can be used as external entropy coder for the CCSDS 123 IP.
SHyLoC as HW accelerator

- Throughput up to 1 Gbps (~60 Msamples/s for 16-bit input) when implemented on a Virtex5 FX130.
- Include AMBA AHB interfaces.
- Compatible with GRLIB and LEON2-FT.
SHyLoC performance

• Compression performance in terms of data reduction depends on the CCSDS standards.
• Performance in terms of throughput, hardware resources and power consumption depends on the selected configuration and target device.

• Mapped to 7 different FPGA devices: Xilinx Virtex 5 & 5QR; Microsemi ProASIC3E, ProASIC3L, RTAX2000, RTAX4000 and RTG4
• Maximum throughput 140 Msamples/s in Virtex5 FX130, 80 Msamples/s in RTG4
• Low complexity: maximum 7% of LUTs Virtex5 FX130 and 13% Microsemi RTG4.
• On demonstrator (Virtex6), throughput of up to 1 Gbps.
SHyLoC availability

- Distributed by the ESA IP Core’s service ([https://www.esa.int/Our_Activities/Space_Engineering_Technology/Microelectronics/SHyLoC_IP_Core](https://www.esa.int/Our_Activities/Space_Engineering_Technology/Microelectronics/SHyLoC_IP_Core))
  
  - ESA/ESTEC maintains and distributes a small catalogue of IP Cores.
  
  - The ESA IP Cores can be licensed for research and/or commercial use, under specific conditions to companies based in ESA members and participants states
  
  - Commercial version by Cobham Gaisler.
CONCLUSION

Compression is an **enabling technology** that **maximizes mission capacities** while **minimizing data rates and volumes and overall costs**

- Only major **drawback** is complex and costly implementation in space HW
  - **Eased by standardization** and “of-the-self” solutions (ESA IP and components)

CCSDS standards to **meet space missions requirements** providing **state-of-the-art performances**

- Large choice depending on:
  - Type of data: 1D, 2D or 3D
  - Type of compression: Lossless, lossy or near-lossless
  - Operating mode: fixed data rate (volume) or fixed quality
  - Memory and computing resources

- Widely available software & hardware implementations

- Large users community and literature