Low-complexity predictive lossy compression of hyperspectral and ultraspectral images

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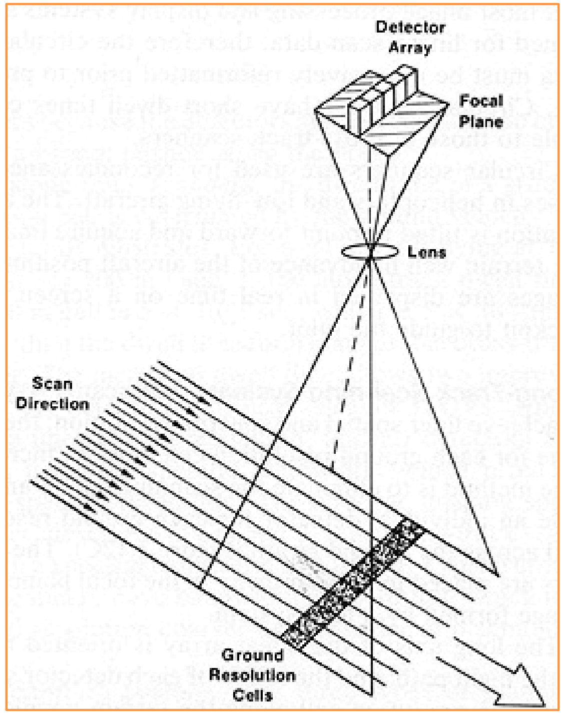
Outline

- Motivation: onboard lossy compression
- Proposed compression algorithm
- Experimental results
- Conclusions

Onboard compression

- Low complexity
- Low buffering requirements
- State-of-the-art compression efficiency
- Should cover bit-rates from 0.5 to 3 bpp
- Some error containment



State-of-the-art

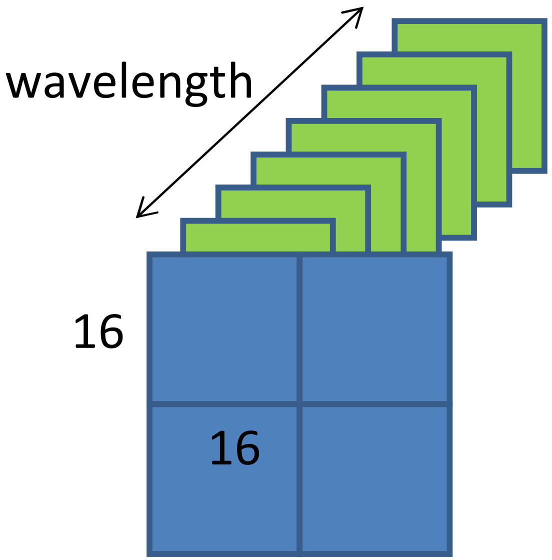
- 3D transform coding (e.g., JPEG 2000 Part 2)
  - → spectral transform (wavelet, KLT, ...)
  - → works well at low bit-rates
  - → high complexity (transform, coding, R/D optimization)
  - → requires line-based spatial transform to accommodate buffering requirements
- 3D prediction
  - → works well at high bit-rates (near-lossless compression)
  - → requires a block coder to go below 1 bpp

Proposed design for onboard compression

- Decorrelation stage: 3D spatial/spectral predictor
  - → very low complexity (comparable with lossless compression)
- What can we do to improve performance at low bit-rates?
  - → Proposed approach: truly lossy compression of prediction residuals
    - improved quantization
    - R/D optimization

Prediction

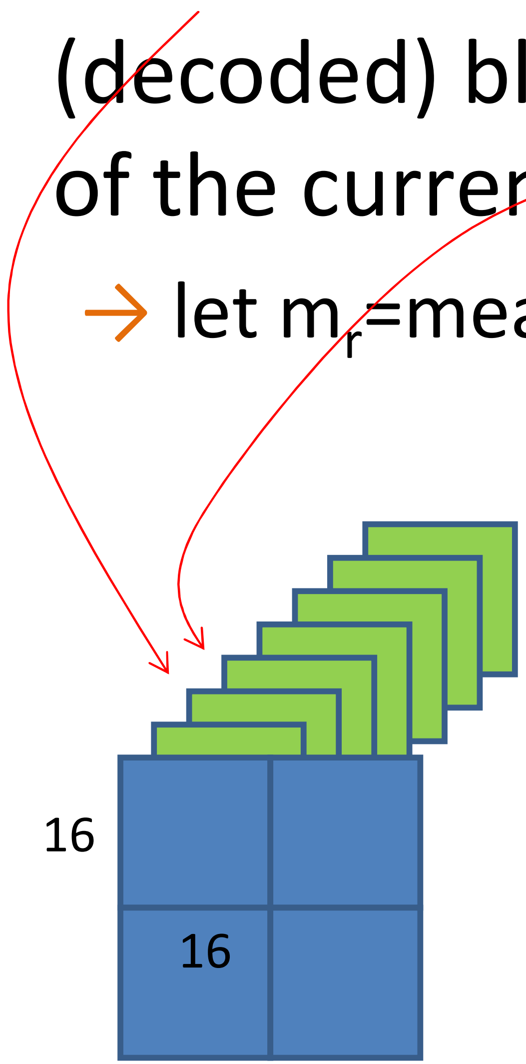
- Prediction is performed independently on 16x16 blocks



- → A block is predicted from the co-located (decoded) block in the previous band
- → A single predictor, defined by two parameters, is used for all samples in the block → low complexity
- → Provides error containment

Prediction

- Let r^T be the vector of samples of the reference (decoded) block, and x^T the vector of samples of the current block
  - → let m_r=mean(r) and m_x=mean(x)



Linear prediction model:

$$x^T \approx \alpha\,(r^T - m_r) + m_x$$

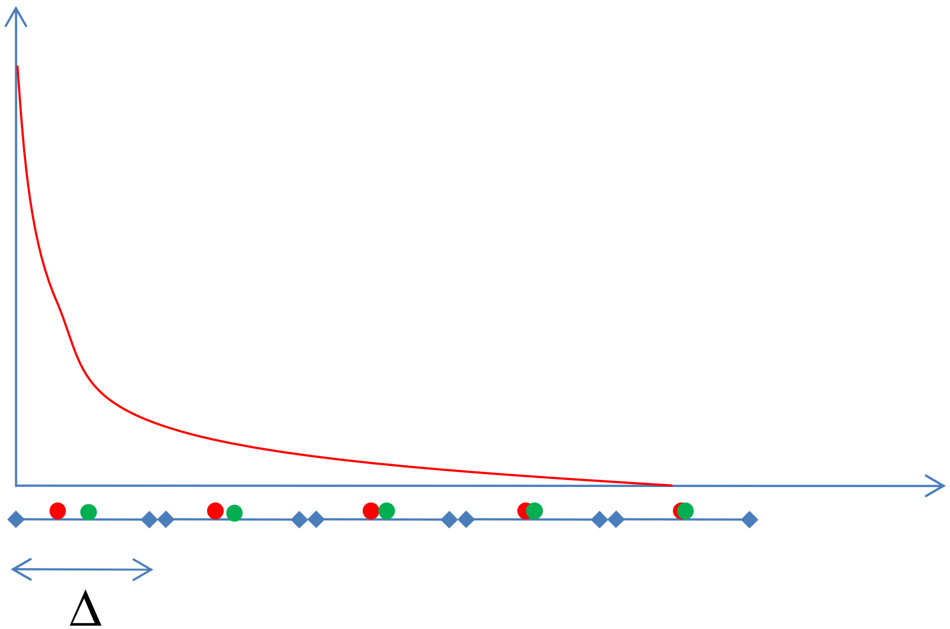
with α minimizing prediction error variance over the block

Quantization

- Scalar uniform quantization followed by entropy coding
  - → near-optimal at high rates, not at low rates
- Quantization with deadzone
  - → near-optimal at low rates, not at high rates
- We decided to use Uniform-Threshold Quantization (UTQ)
  - → near-optimal at all rates, slightly more complex

UTQ

- It is a scalar quantizer in which the intervals are uniform
  - → but the reconstruction values are taken as the centroids of each interval (**red** dots), and not the midpoint (**green** dots)



R/D optimization

- Idea: certain 16x16 blocks can be predicted extremely well
  - → we do not encode the prediction error → SKIP mode
- In particular:
  - → after prediction, we compute the variance of the prediction error, D
  - → we compare D with a threshold: $D \geq \frac{\Delta^2}{4}$
  - → if D exceeds the threshold, we encode the prediction error
  - → otherwise we simply write the prediction parameter for the block

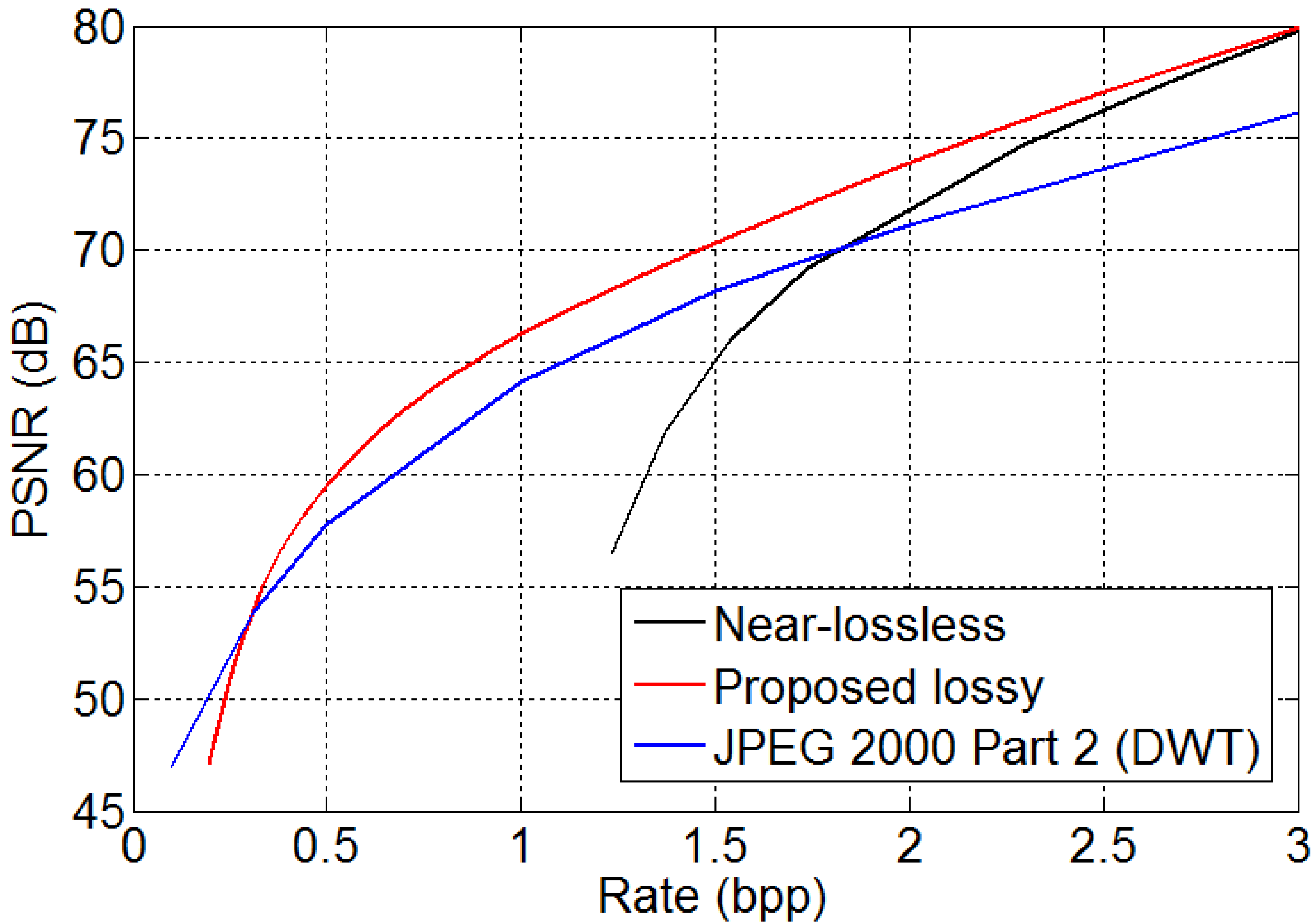
Coding

- Coding of prediction residuals
  - → Mapped prediction residuals are coded using a Golomb power-of-two code
  - → Code parameter selection for each sample is based on the accumulated magnitude of unmapped residuals over a window of past samples

Results

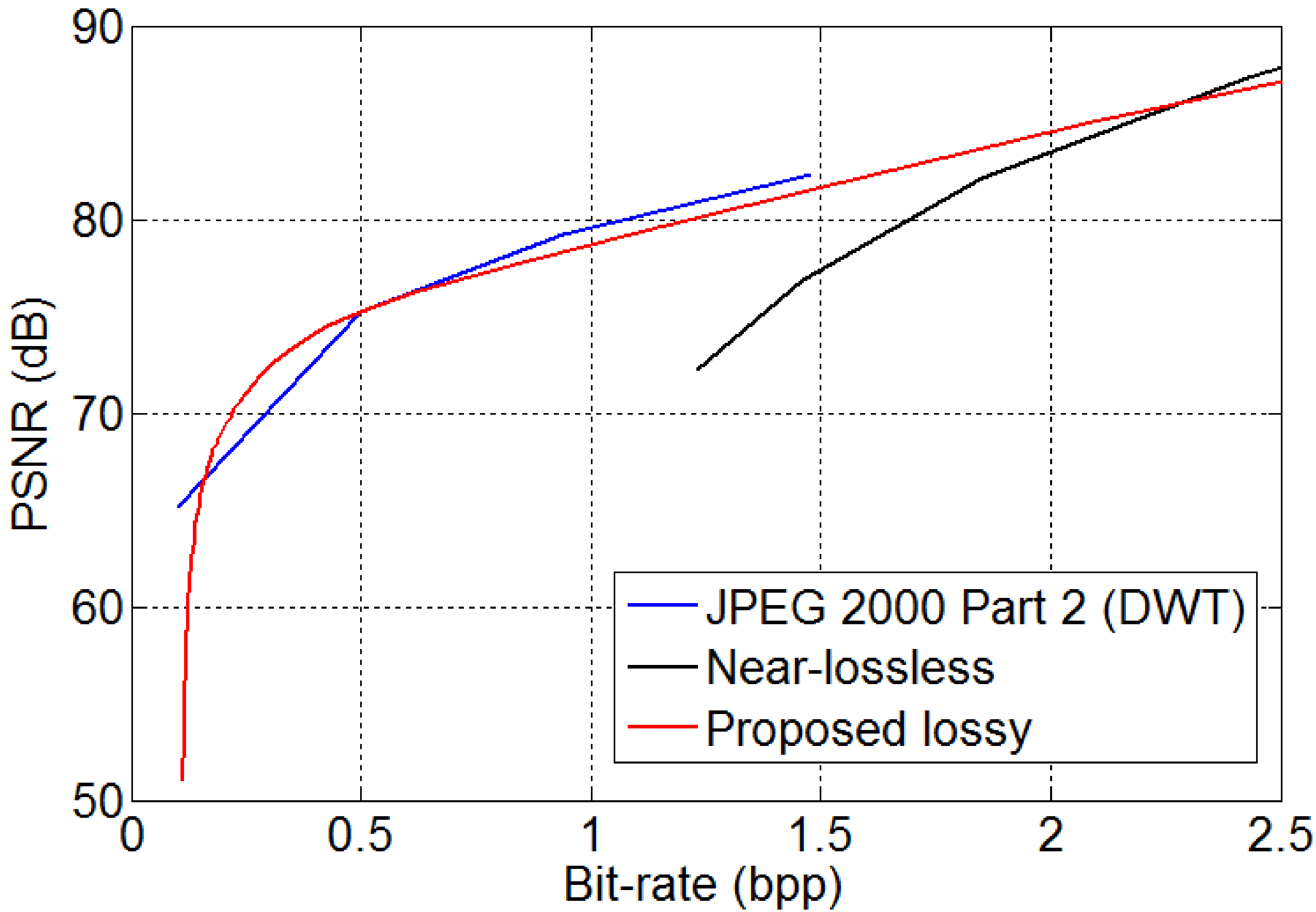
- Dataset
  - → **Aviris** raw images (Yellowstone), *sc0* scene (680x512x224)
  - → **AIRS** sounder image, *granule9*, 135x90x1501
- We look at PSNR
- We compare with
  - → JPEG 2000 Part 2 with spectral DWT (VM8.6)
    - full 3D R/D optimization, no line-based transform
  - → near-lossless compression using same predictor and entropy coder, but scalar uniform quantizer and no R/D optimization

AVIRIS



80
75
70
65
60
55
50
45
0
0.5
1
1.5
2
2.5
3
PSNR (dB)
Rate (bpp)
Near-lossless
Proposed lossy
JPEG 2000 Part 2 (DWT)

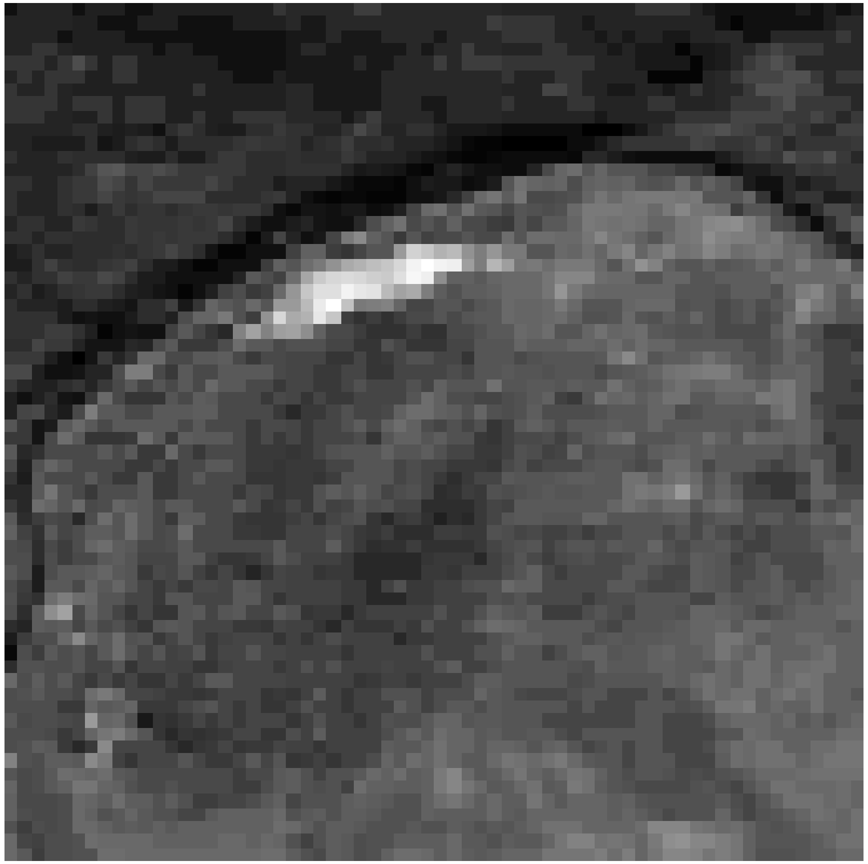
AIRS



90
80
70
60
50
PSNR (dB)
0
0.5
1
1.5
2
2.5
Bit-rate (bpp)
JPEG 2000 Part 2 (DWT)
Near-lossless
Proposed lossy

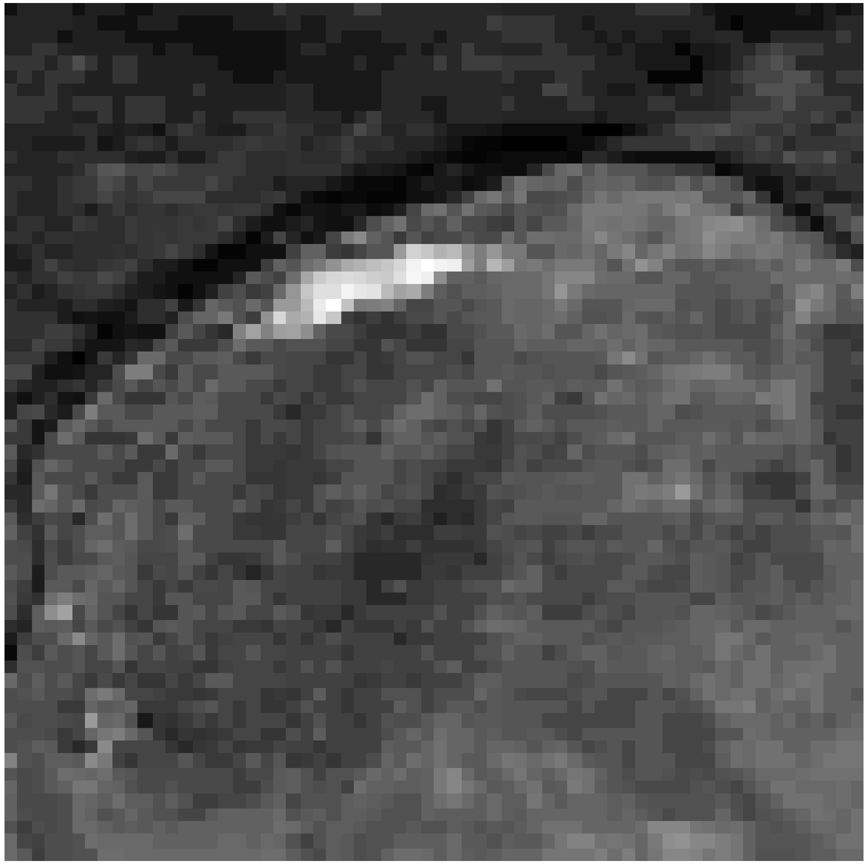
Visual quality

- original (*sc0* band 63)



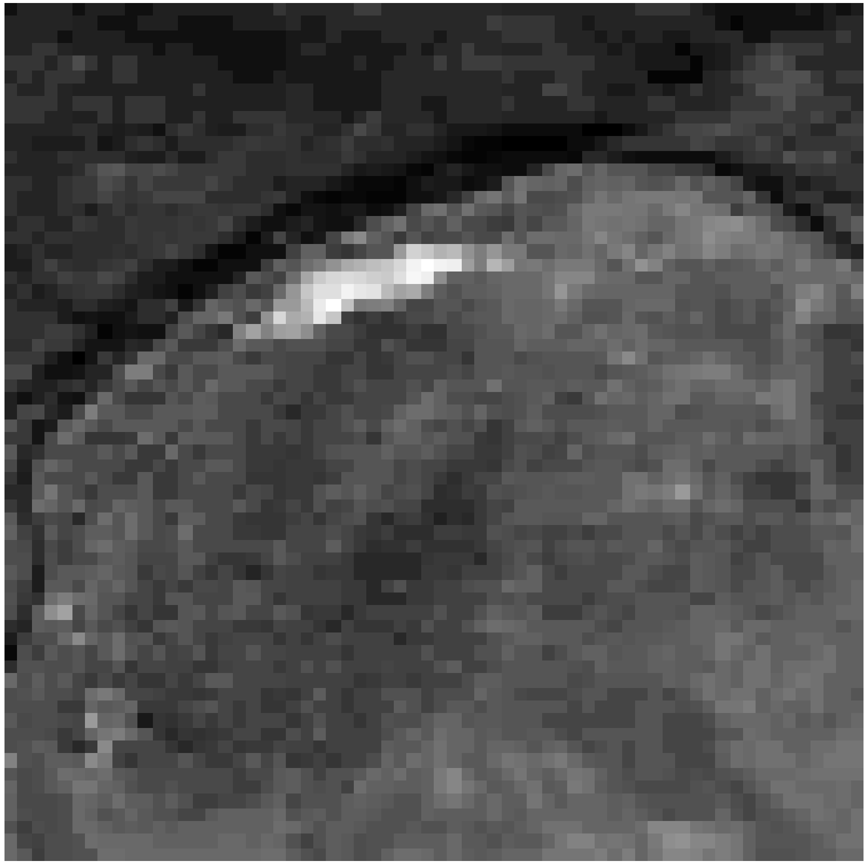
Visual quality

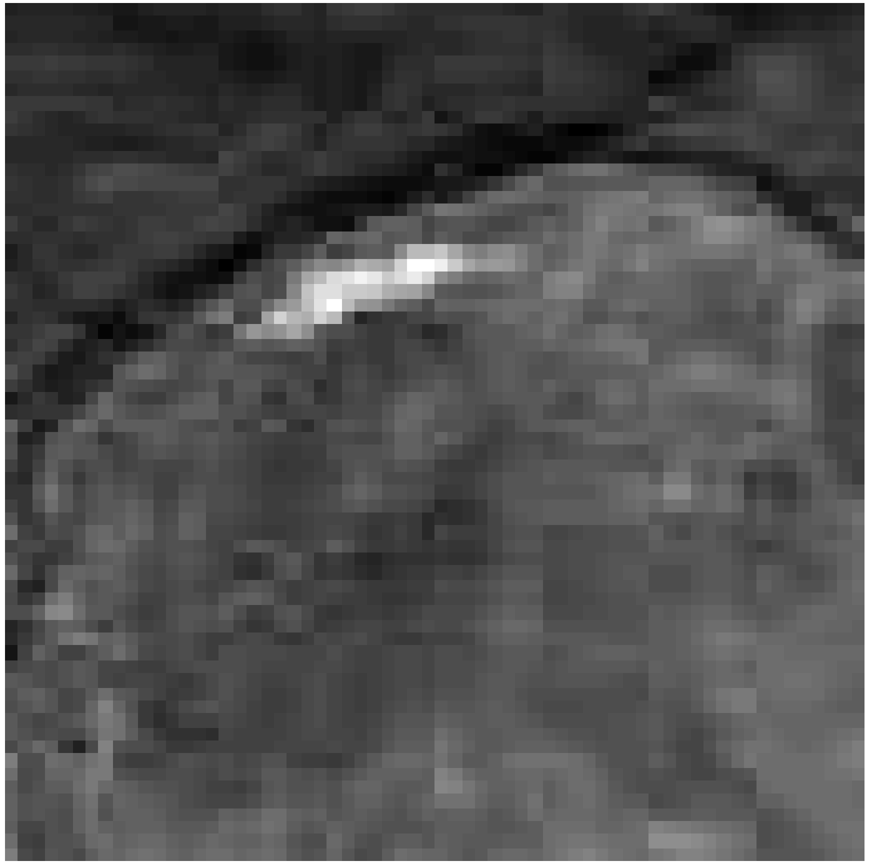
- reconstructed (0.14 bpp)



Visual quality

- JPEG





More on visual quality

- Scalar quantization in pixel domain
  - → errors are independent from pixel to pixel
  - → no blocking artifacts
  - → no “cross-talk” (quantization error on one “big” transform coefficient can bias the reconstructed value of several neighboring “small” pixels)

Conclusions

- Proposed prediction-based algorithm for onboard lossy compression
  - → performance equal or better than state-of-the-art
  - → complexity and memory requirements significantly lower
    - ~10 times fewer operation than JPEG2000 with spectral DWT
  - → still room for improvement
    - block/arithmetic coding
    - optimal band ordering
    - rate control
- Algorithm under evaluation for spectral imager carried on ESA ExoMars rover

UTQ - details

- The reconstruction process requires to estimate the variance of the prediction error
  - → using a Laplacian assumption, we get this parameter as the ratio of the number of coefficients N1 and N2 quantized to values 1 and 2 by a scalar uniform quantizer
  - → then we calculate a correction term as follows:

$$T = \frac{1 - \gamma e^{-\gamma} / (1 - e^{-\gamma})}{\gamma} \qquad \gamma = \log(N1 / N2)$$