Perceptual Evaluation of Lossy Compression Techniques in Synchrotron Tomography: Bridging Visual and Quantitative Measures

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Data compression is becoming a critical necessity for high throughput synchrotron radiation experiments like Computed Tomography (μ-CT), where the bit depth, data rate, and detector size continue to increase, contributing to the so-called “data deluge” [1]. Previous studies of data compression frameworks for μ-CT based on JPEG-XR [2] highlighted that lossy methodologies can be a suitable alternative [3,4] to lossless ones. However, the limitation of certain codecs to operate only on integer data may pose a challenge for detector systems, particularly those integrating edge-computing capabilities (e.g. averaging/combining exposures, de-noising, calibration, HDR frames).

This work focuses on the perceptual evaluation [5,6,7] of lossy data compression techniques designed specifically for X-ray tomography; following the steps of medical imaging [5,6], we investigate data compression for μ-CT using modern perception-based quality metrics such as 4-MS-G-SSIM [5] and HDR-VDP3 [7] (applied end-to-end) which have been proved to be “good surrogates of a radiologist” [5]. By comparing these metrics with a loss function based on Fourier Ring Correlation (FRC) [8], a quantitative measure commonly used to estimate resolution in computational imaging, we aim to bridge the gap between visual quality metrics and quantitative measures like FRC. Additionally, we extend previous studies by evaluating the efficacy of compression techniques on floating-point 32-bit data, to accommodate for future detector requirements and advanced pre-processing.

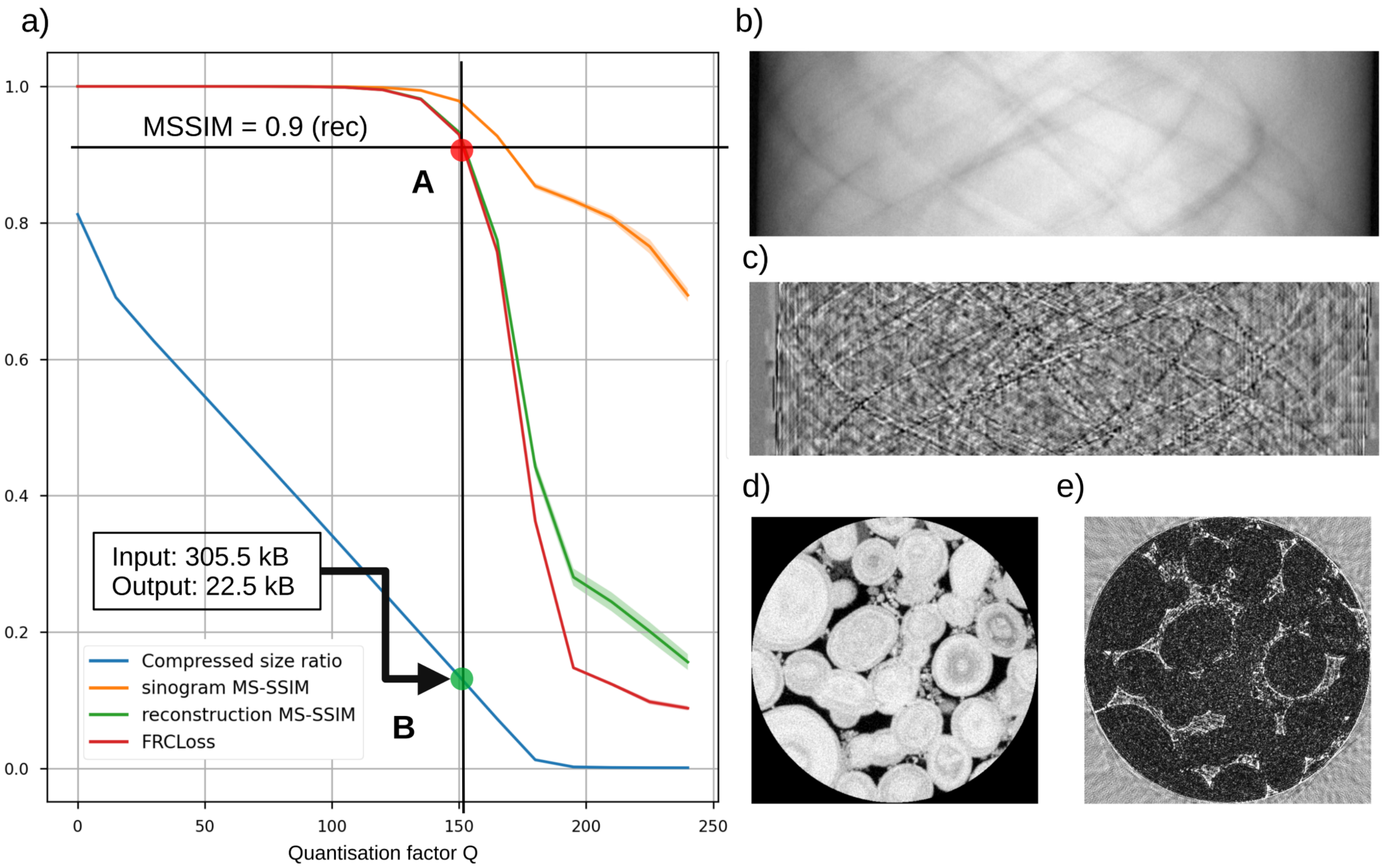

Fig 1. Comparison of 4-MS-SSIM (green curve) and FRCLoss (red curve) computed on the reconstruction of a kettocarbonate μ-CT dataset (open data available at [9]) (panel a) as a function of the quantisation factor Q, which is an integer parameter [0-255] of the jpeg-xr encoder [10]. The Q parameter, controls the balance between image quality and file size (0: no compression, 255: maximum compression). Notably, both metrics exhibit the same trend, particularly evident at the knee point where they both reach 0.9 (point A) for Q = 150 (nearest computed value). Comparing the corresponding file sizes (point B, intercept with the compressed file size curve – blue), the compression is of a factor of 14. The other panels show (for the same Q value) respectively: the decompressed sinogram (b), the rawdata – compressed difference (c), the reconstructed slice (d) and its difference with the ground truth (e) [9].

REFERENCES:

[1] R. Rao, “Synchrotrons face a data deluge,” Physics Today, vol. 2020, no. 2. AIP Publishing, p. 0925a, Sep. 25, 2020, http://dx.doi.org/10.1063/PT.6.2.20200925a

[2] L. Mancini et al., “About a method for compressing x-ray computed microtomography data,” Measurement Science and Technology, vol. 29, no. 4. IOP Publishing, p. 044002, Mar. 08, 2018. doi: 10.1088/1361-6501/aaa0fa. Available: http://dx.doi.org/10.1088/1361-6501/aaa0fa

[3] F. Marone et al., “Impact of lossy compression of X-ray projections onto reconstructed tomographic slices,” Journal of Synchrotron Radiation, vol. 27, no. 5. International Union of Crystallography (IUCr), pp. 1326–1338, Jul. 28, 2020, http://dx.doi.org/10.1107/S1600577520007353

[4] F. Alted et al., Blosc2, Grok and JPEG2000, online https://github.com/Blosc/leaps-examples

[5] G. P. Renieblas et al., “Structural similarity index family for image quality assessment in radiological images,” Journal of Medical Imaging, vol. 4, no. 3. SPIE-Intl Soc Optical Eng, p. 035501, Jul. 26, 2017, http://dx.doi.org/10.1117/1.JMI.4.3.035501

[6] K. J. Kim et al., “A Comparison of Three Image Fidelity Metrics of Different Computational Principles for JPEG2000 Compressed Abdomen CT Images,” IEEE Transactions on Medical Imaging, vol. 29, no. 8. Institute of Electrical and Electronics Engineers (IEEE), pp. 1496–1503, Aug. 2010, http://dx.doi.org/10.1109/TMI.2010.2049655

[7] R. K. Mantiuk et al., “HDR-VDP-3: A multi-metric for predicting image differences, quality and contrast distortions in high dynamic range and regular content.” arXiv, 2023, https://arxiv.org/abs/2304.13625

[8] N. Banterle et al., “Fourier ring correlation as a resolution criterion for super-resolution microscopy,” Journal of Structural Biology, vol. 183, no. 3. Elsevier BV, pp. 363–367, Sep. 2013, http://dx.doi.org/10.1016/j.jsb.2013.05.004

[9] A. Singh et al., “On Representative Elementary Volumes of Grayscale Micro-CT Images of Porous Media,” Geophysical Research Letters, vol. 47, no. 15. American Geophysical Union (AGU), Aug. 07, 2020, http://dx.doi.org/10.1029/2020GL088594

[10] JPEG-XR reference code, online https://jpeg.org/downloads/jpegxr/jpegxr-ref.zip