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INTERFERE: A Unified Compression Framework for Digital Holography

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Abstract: Large data-rates together with a variety of formats, incurred by digital holographic applications, pose barriers to storage, transmission and interoperability. A compression solution designed for addressing these concerns is proposed.

1. Introduction

Efficient compressed digital representations are of utmost importance in making holographic techniques practical. There are several challenges particular to holography, of which the most pressing is the data deluge arising from computer-generated holograms (CGH) at a nm scale and the very high entropy of interferometric data. Another aspect is related to the diversity of hologram properties seen across various application modalities, for example when comparing multimedia visualization and metrology in microscopy.

In this context, the JPEG committee has launched the development of the JPEG Pleno standard. It aims at providing efficient compression, but also to ensure interoperability between various holographic devices and even between various plenoptic modalities including lightfields and pointclouds. Recently, a call for proposals [1] was published by the committee for identifying promising compression techniques towards this goal. In this abstract, we summarize the INTERFERE framework which was submitted by VUB-imec, as a baseline for standardization.

2. Compression methodology

The INTERFERE compression solution consists currently of two modes: one for lossy compression of holograms represented with greyscale levels and another for lossless compression of bi-level holograms as outlined below.

2.1. INTERFERE mode I - STFT with adaptive quantization for greyscale levels

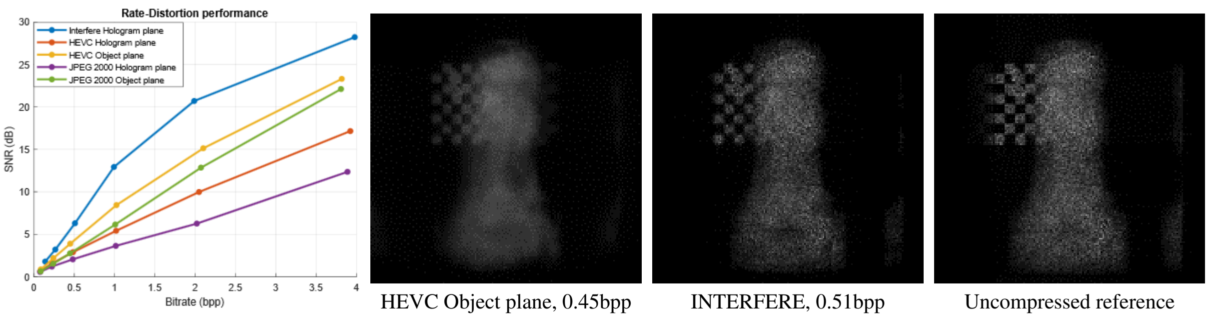
For storing holographic wavefields with greyscale levels, we propose to use the orthornormal 2D-STFT (short time Fourier transform) that uses rectangular windows with zero overlap for sparsifying the signal [2]. Each transform coefficient refers to the complex amplitude of the wavefield received in the spatial segment under the corresponding rectangular window along some particular direction.

For a given spatial region in a typical hologram, only certain frequency regions are activated depending on the geometrical position of the region with respect to the objects in the scene. Furthermore, depending on the position and viewing orientation of the user with respect to the scene space, only a subset of the entire hologram needs to be relayed at a given time. Here, the STFT can not only localize the energy of the hologram to a few coefficients, but also enable random access in space and frequency. The transform (and its inverse) can be calculated efficiently with complexity $O(n \log n)$ using a cascade of row-wise and column-wise FFTs.

After obtaining the transform coefficients, we group nearby coefficients in space and frequency into a 4D structure termed QB (quantization block) for the purpose of adaptive quantization. Each QB is assigned a separate mid-rise quantizer (MRQ) with a bespoke quantization range and quantization bit depth.

For each QB and each candidate bit depth, we determine the optimal value of the quantization range using numerical optimization techniques. Since the quantization range needs to be also stored for each QB, it is also quantized. Another MRQ is used, where the quantization ranges belonging to the same QB bit depth are assigned a separate quantizer. The bit depth allocation for the QB transform coefficients and range is determined by a two stage Lagrangian rate-distortion optimization strategy.

Finally, the quantization bit depth, ranges and the coefficients belonging to QBs from nearby spatial and frequency regions are grouped into codeblock units for entropy coding. Per 4D codeblock, one adaptive context model is used for encoding the QB bit depths, while zero-order adaptive context models are used for encoding the QB coefficients and range. Each codeblock can be decoded independently allowing for 4D random access.



HEVC Object plane, 0.45bpp INTERFERE, 0.51bpp Uncompressed reference

Fig. 1: Objective and subjective evaluation of compression errors observed with ”Deep chess” hologram.

2.2. *INTERFERE mode II - adaptive context modelling for binary level*

Binary signals oscillate between two states and are non-smooth, which results in limited applicability of sparsifying transforms that are usually non-binary. As a consequence, in image compression techniques like JBIG/JBIG2 use a statistical model with an adaptive entropy coder. In such approaches, the probability estimate of the current pixel being encoded is utilized by the entropy coder, where the degree of compression achieved increases as the uncertainty governing the pixel decreases.

For binary hologram compression, we propose to use an alternative Bayesian context modelling approach, under the assumption of unknown priors. The probability estimate is conditioned explicitly only with respect to a few pixels located at close proximity with respect to the current pixel, also known as the context. In our proposal, the context pixels used are determined in a dynamic manner, where the context size with the minimum expected bitrate is chosen at a given time.

However, these statistical techniques assume a stationary signal, where the probability of the current pixel given some context is the same for any region in the hologram. Holograms are approximately quasi-stationary on some scale, where the probability estimate slowly drifts across the entire hologram. Thus applying adaptive context-based techniques directly on the entire hologram is usually sub-optimal and a quad-tree based spatial segmentation scheme is used instead.

3. Results and conclusion

The rate-distortion performance of the INTERFERE mode I - STFT is shown in Figure 1 for the representative standard test ”Deep chess” hologram with distortion measured in terms of signal-to-noise ratio (SNR). The performances of H.265/HEVC in its intra compression mode and JPEG 2000 under both hologram plane compression and object plane compression are shown as anchors [3].

Even with the application of object plane compression, involving a transformation of input data, our compression proposal can obtain significantly lower bit rates for the same target SNR when compared to the anchors. The performance improvement can be also seen under subjective testing in the representative views, where energy is concentrated among higher spatial frequencies. In comparison to the best-performing mode for H.265/HEVC, contrast and details are well preserved with the hologram-domain INTERFERE compression framework.

The bitrates obtained by INTERFERE mode II for lossless compression of binary holograms were compared with JBIG2 and yield bit rates improvements of 4.6% (”Wolf”), 12.2% (”Dragons”), 15.1% (”Aeroplane”), 11.4% (”Cornel box”) and 11.1% (”Deep Cornell box”). In view of these positive early evaluations, the unified INTERFERE compression proposal with both these lossy and lossless modes was finally chosen by the JPEG Pleno committee for further development as a future standard for compression of digital holograms.

4. Acknowledgements

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