Compression challenges for digital holography

Peter Schelkens[1,2,*], David Blinder[1,2,3], Raees Kizhakkumkara Muhamad[1,2], Saeed Mahmoudpour[1,2], Colas Schretter[1,2] and Tomoyoshi Shimobaba[3]

[1] *Department of Electronics and Informatics (ETRO), Vrije Universiteit Brussel (VUB), Pleinlaan 2, B-1050 Brussel, Belgium.*
[2] *IMEC, Kapeldreef 75, B-3001 Leuven, Belgium.*
[3] *Graduate School of Engineering, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba, Chiba, Japan*

[*] *peter.schelkens@vub.be*

Abstract: Interoperability between holographic devices and application pipelines is an important functionality to guarantee the smooth integration of products and services. This also requires suitable data formats at the different stages of a holographic signal processing chain.

1. Introduction

While we observe an increasing maturity of holographic imaging and visualization devices, it is also important to guarantee interoperability in terms of data (coding) formats issued between devices and/or applications. However, this aspect has received little attention so far. It has — to our knowledge — only been addressed by one standardization body, namely ISO/IEC JTC 1/SC 29/WG 1, i.e., the JPEG committee, in the context of the JPEG Pleno Holography standard (ISO/IEC 21794-5) that is planned to be officially released in 2024 [1] (see Figure 1).

However, interoperability is compromised by the large heterogeneity in terms of capturing, generation, processing, and rendering techniques and equipment deployed in applications such as microscopy and visualization. For example, spatial light modulators operate based on amplitude or phase modulation and accept binary- or integer-valued data [2]. Streaming applications require random access to the compressed data to support particular viewing angles and impose space-frequency domain segmentation to facilitate this functionality. Microscopy and tomography will require different data formats when representing data in holographic and reconstruction domains. Classical coding solutions are often inadequate for holographic representations [2].

Moreover, particularly visualization, but also microscopy or tomography (for e.g., medical applications), require or result in very large holograms orders of magnitude beyond nowadays display resolutions. Hence, this not only requires a very efficient compression solution in terms of rate-distortion performance but also in terms of memory footprint and behaviour with respect to the underlying hardware architectures.

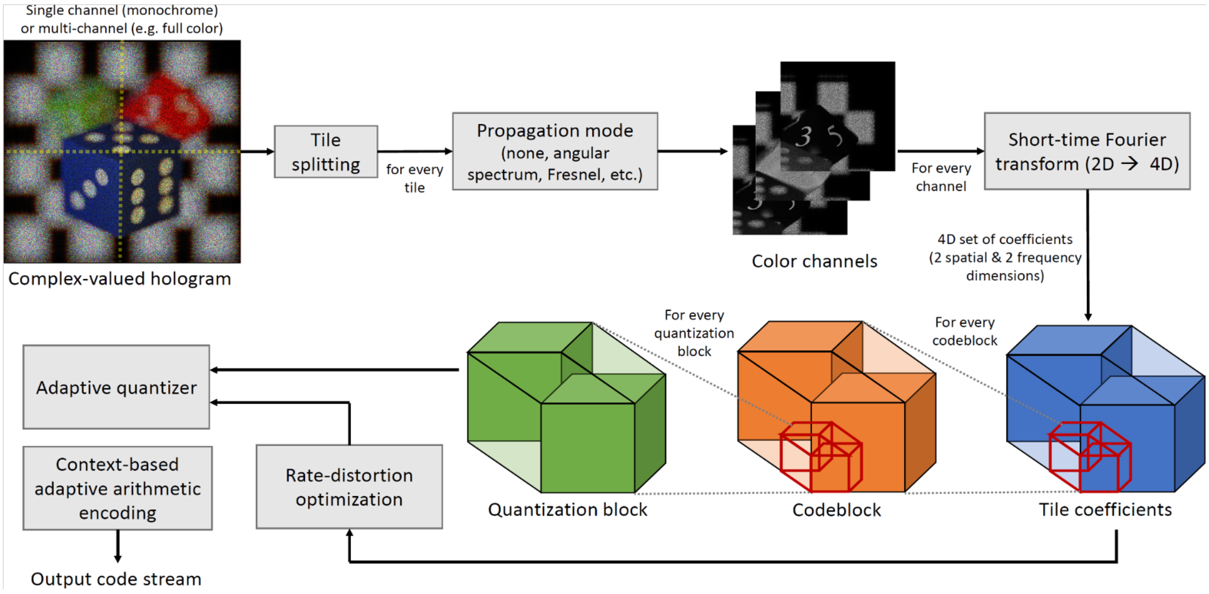

Fig. 1: Encoder architecture for JPEG Pleno Holography, the international coding standard for holographic content.

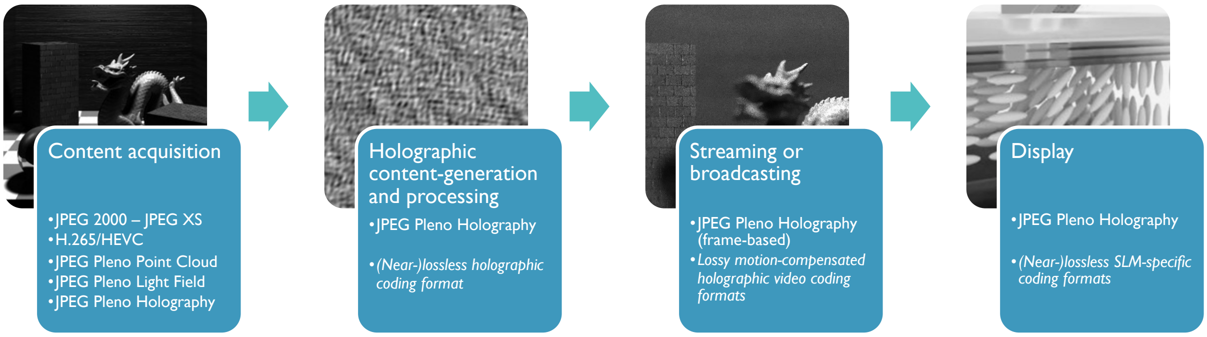

Fig. 2: End-to-end holographic signal processing chain illustrating the compression needs at every stage.

2. Data formats and associated coding solutions

Given the plethora of holographic devices and applications, one solution fits all does not exist. However, for imaging and visualization applications, nowadays, different coding solutions are deployed to handle different functionality and bandwidth requirements across an end-to-end application chain. For digital television, content captured with a digital camera is first compressed in a (near-)lossless — often proprietary — format, whereas during postproduction, a (near-)lossless frame-based compression (e.g. JPEG 2000 or H.265/HEVC-intra with 10 or 12-bit precision) is deployed. Thereafter the content is transcoded for broadcasting or streaming using a lossy inter-frame coding solution (e.g. HEVC-inter). Subsequently, the content is often transcoded to a (near-)lossless format (e.g. JPEG XS) at the client side to transmit +4K content with HDMI cables to the display.

For holographic visualization, similar scenarios, such as those illustrated in Figure 2, are imaginable. Conceptually, the source material serving as input for the content generation will be delivered in their native acquisition format, preferably at a sufficient high-quality level, typically (near-)losslessly compressed. The computer-generated and processed hologram will then successfully be stored in a high-quality format that contains all the required attributes and typically requires a complex-valued representation. For streaming or broadcasting, the hologram will be downconverted to a representation that facilitates the typical display and end-user requirements regarding quality and functionality (supported viewing angle range, viewing cone selection...). Finally, inside the display device, a format will be issued that matches the internal bandwidth requirements imposed by the display hardware.

Similarly, for microscopy chains, alike problems exist. Data in the acquisition domain might be of different nature depending on the imaging modality (e.g. off-axis holograms, interferograms, Fourier-ptychographic recordings). In contrast, the reconstruction data (e.g. flat or volumetric maps of phase information or refractive indices) live in a completely different representation space requiring more classical image and volumetric coding solutions (e.g. JPEG 2000 Part 12 – Volumetric coding of data). Therefore, having a nuanced understanding of the targeted application domains is critical to making the appropriate strategic decisions to choose off-the-shelf standardized solutions, proprietary data formats, or launch new standardization efforts.

3. Future challenges

It is apparent that the holographic pipeline is still sparsely supported by coding formats, and further efforts are needed to forward interoperability in holographic ecosystems. Many open challenges lie ahead of us. To enumerate a few: colour decorrelation or single holograms with multi-colour support, holographic video coding with motion compensation that can handle interferometric data, quality assessment techniques able to model the perception of the human visual system for holographic content, and convincing deployment of deep learning strategies [3].

Funding

Research Foundation – Flanders (FWO) (G0B3521N, 12ZQ223N, VS07820N); Japan Society for the Promotion of Science (International research fellow P22752); Korean Institute for Advancement of Technology (KIAT, P146500071).

Funding

P. Schelkens, D. Blinder, R. K. Muhamad, S. Mahmoudpour, C. Schretter, and T. Shimobaba, "Compression challenges for digital holography," in Optica Imaging Congress (3D, COSI, DH, FLatOptics, IS, pcAOP), Technical Digest Series (Optica Publishing Group, 2023), paper HW4C.1.

Published open access under embargo of 12 months

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