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Compression of Digital Holographic Data: an Overview

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ABSTRACT

Holography has the potential to become the ultimate 3D experience. Nevertheless, in order to achieve practical working systems, major scientific and technological challenges have to be tackled. In particular, as digital holographic data represents a huge amount of information, the development of efficient compression techniques is a key component. This problem has gained significant attention by the research community during the last 10 years. Given that holograms have very different signal properties when compared to natural images and video sequences, existing compression techniques (e.g. JPEG or MPEG) remain suboptimal, calling for innovative compression solutions. In this paper, we will review and analyze past and on-going work for the compression of digital holographic data.

Keywords: Digital holography, computer generated holography, wavelets, direction-adaptive discrete wavelet transform, packet decompositions, vector lifting scheme, JPEG 2000, image compression

1. INTRODUCTION

Three-dimensional (3D) imaging has the potential to greatly enhance user experience. It is therefore considered as a key technology in a broad range of applications including 3D cinema, 3DTV, immersive communications, video games, medicine, video protection, and manufacturing. An overview of state-of-the-art and emerging technologies is presented in [1].

However, current solutions based on stereoscopic vision only exploit limited depth-cues and suffer from intrinsic limitations. Conversely, holography offers the potential of the ultimate 3D experience by fully reconstructing the wavefront of the object or scene. In particular, holography can provide continuous head motion parallax, natural eye vergence and accommodation, and all depth-cues.

Holography has already been successfully applied in a number of applications, notably interferometric microscopy and metrology. However, significant scientific and technological hurdles will have to be addressed before viable and practical solutions appear for a broader range of applications such as 3DTV. Signal processing challenges related to wave propagation, diffraction and holography are analyzed in [2][3]. Recent developments in holographic displays are discussed in [4].

In this paper, we more specifically consider the problem of compression in holography. To fulfill its promises, holographic systems and displays need to handle full horizontal and vertical parallax, with high-resolution images, and hence require a very high bandwidth. Moreover, the signal properties of holograms differ significantly from those of natural images and video sequences. Consequently, the simple application of existing image and video compression

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techniques, such as the family of JPEG and MPEG standards, remain suboptimal, and new techniques are needed in order to better represent holographic data.

The remaining of this paper is structured as follows. Some background concepts about holography are briefly reviewed in Sec. 2. We discuss the state-of-the-art for holographic data compression in Sec. 3, including quantization-based, transform-based and standard-based methods. We also present in more details two recently proposed schemes based on JPEG 2000. Finally, we make concluding remarks and discuss open issues and perspectives in Sec. 4.

2. BACKGROUND ON HOLOGRAPHY

Holography was invented by Dennis Gabor in 1948 [5]. A hologram records the light field emanating from a scene as an interference pattern which subsequently allows reproducing this same light field. Thanks to the advent of digital technologies, Digital Holography (DH) consists in numerically recording holograms with a light-sensitive sensor such as a Charged Coupled Device (CCD). In turn, the procedure can be computationally simulated with Computer Generated Holography (CGH). In this section, we briefly review some basic concepts about DH and CGH.

2.1. Digital Holography

A holography setup schematically involves a laser beam, as a source of coherent light, and a beam splitter, which divides the light into an object beam, which illuminates the object and a reference beam. The hologram is obtained by recombining and superposing the two beams, then recording the resulting interference pattern. The setup is illustrated in Figure 1.

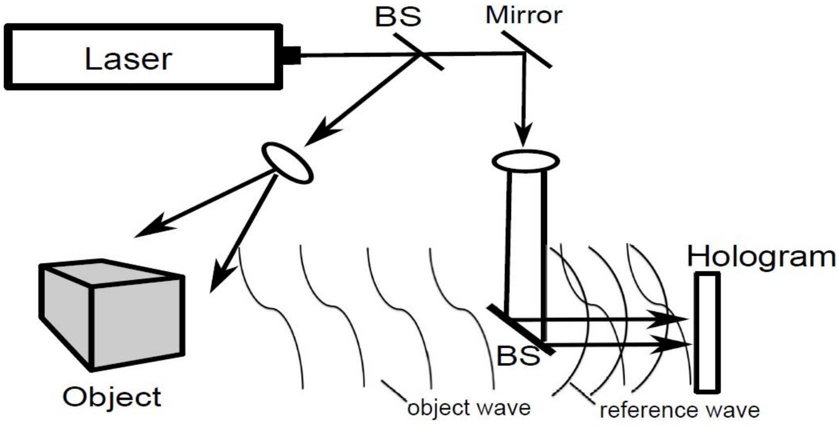

Figure 1 – Holography setup (BS=Beam Splitter).

More formally, denoting the reference wave by U_R and the object wave by U_O, the hologram is expressed by

$$I_H = |U_R + U_O|^2 = |U_R|^2 + |U_O|^2 + U_R U_O^* + U_R^* U_O \ , \tag{1}$$

where * is the complex conjugate operator. We can observe that the interference pattern is composed of four terms: the first and second terms correspond to zero-order diffraction, the third one is the real image (also referred to as twin or conjugate image), and the forth one is the virtual image.

Several methods have been proposed to separate these different images. With off-axis holography [6], the reference beam is incident with an offset angle when interfering with the object beam in the hologram plane. In turn, the resulting zero-order, real and virtual images are spatially separated. An alternative is to use phase-shifting holography [7]. More specifically, multiple holograms are recorded using Phase-Shifting Interferometry (PSI).

2.2. Computer Generated Holography

With CGH, the light wave propagation can be simulated by numerical computations. The reconstruction procedure is the result of a diffraction phenomenon when the reference beam illuminates the hologram, which acts as an aperture. Supposing that the reference beam is perpendicular to the hologram plane, the complex amplitude of the reconstructed image $U(\xi,\eta)$ is given by the Fresnel-Kirchhoff diffraction

$$U(\xi,\eta) = -\frac{i}{\lambda}\iint I_H(x,y)U_R(x,y)\frac{e^{ikr}}{r}dxdy \ , \tag{2}$$

where (ξ,η) are the coordinates in the image plane, (x,y) are the coordinates in the hologram plane, d is the distance between the two planes, λ is the wavelength of the reference wave and k the wavenumber, and the distance r between the points (x,y) and (ξ,η) is given by

$$r = \sqrt{(x-\xi)^2 + (y-\eta)^2 + d^2} \ . \tag{3}$$

To compute more effectively the integral in Eq. (2), the distance r is approximated by taking the Taylor series expansion and discarding the fourth and higher terms

$$r \approx d + \frac{(x-\xi)^2}{2d} + \frac{(y-\eta)^2}{2d} \ . \tag{4}$$

Substituting this expression in Eq. (2), and further approximating the denominator r by d, the Fresnel approximation is obtained

$$U(\xi,\eta) = -\frac{i}{\lambda d}e^{ikd}\iint I_H(x,y)U_R(x,y)e^{\frac{ik}{2d}\left[(x-\xi)^2+(y-\eta)^2\right]}dxdy \ . \tag{5}$$

This equation can then be discretized and computationally solved using a Fast Fourier Transform (FFT).

2.3. Data Representations

Holograms can be represented in a number of ways, as detailed hereafter. The different representations are equivalent, up to the precision of computations, in the sense that they reconstruct the same object. However, some of them may be more suitable for compression.

2.3.1. Intensity-based Representation

This representation directly corresponds to the real-valued intensity of the interference patterns $I_H(x,y)$, as defined in Eq. (1), which are acquired by the sensor device or simulated by CGH.

As mentioned above, in order to separate the zero-order, real and virtual images, off-axis holography can be used. The advantage of this method is that one recording is sufficient, but the drawback is that it puts more constraints on the acquisition.

Conversely, phase-shifting holography can be used in an on-axis setting. In this case, multiple recordings, with known shifted phases for the reference beam, are needed to retrieve the complex amplitude values of the object wave. Obviously, the drawback is that the resulting raw data rate is increased and recording of dynamic scenes becomes cumbersome. In [8], observing that these multiple recordings are correlated, a shifted distance representation is defined as the differences of phase-shifted holograms:

$$\begin{cases} D^{(1)}(x,y) = I_H(x,y,\phi_1) - I_H(x,y,\phi_2) \\ D^{(2)}(x,y) = I_H(x,y,\phi_2) - I_H(x,y,\phi_3) \end{cases} . \tag{6}$$

2.3.2. Complex Wavefield Representation

From the interference patterns and Eq. (5), it is possible to compute the complex amplitude values of the reconstructed image $U(\xi,\eta)$, which is the most complete representation of the wavefield. Straightforwardly, this complex number can be expressed in two equivalent ways: as real-imaginary format

$$U(\xi,\eta) = \mathrm{Re}(U(\xi,\eta)) + i \cdot \mathrm{Im}(U(\xi,\eta)) \ , \tag{7}$$

or amplitude-phase format:

$$U(\xi,\eta) = A(\xi,\eta) \cdot e^{i\phi(\xi,\eta)} \ . \tag{8}$$

3. OVERVIEW OF HOLOGRAPHIC DATA COMPRESSION

Rapid progresses in computer technology and digital signal processing have opened new opportunities and avenues for digital holography. However, several important challenges remain to fulfil the vision of holography as the ultimate 3D experience and to enable new applications. One of these challenges is the large volume of data generated by digital holography. In this section, we review past and current works on the compression of holographic data.

3.1. Quantization-based methods

Earlier attempts at holographic data compression investigated the performance of lossless coding. In [9], several lossless coding techniques, namely Lempel-Ziv, Lempel-Ziv-Welch, Huffman and Burrows-Wheeler, are applied on holograms created by phase-shifting interferometry. On the one hand, it is shown that compression of amplitude and phase components performs poorly, reaching on average a compression ratio of 1.33. On the other hand, applying the same lossless coding techniques on a real-imaginary representation leads to better performance, with an average compression ratio of 4.66. Nevertheless, the presence of speckle noise seems to negatively impact the performance.

If lower bit rates are required, it is obvious that lossy compression techniques need to be applied. For this purpose, several lossy compression schemes are also investigated in [9]: subsampling, quantization, and Discrete Fourier Transform (DFT). In these experiments, normalized cross-correlation is chosen as distortion metric, as the paper is targeting 3D pattern recognition applications. It is first shown that digital holograms are very sensitive to subsampling. In contrast, uniform quantization proves to be much more effective. A compression ratio of 16 is achieved, using a real-imaginary representation, while maintaining a good reconstructed quality with a normalized cross-correlation greater than 0.98.

The effect of uniform quantization of holograms is also investigated in [10], in both numerical simulation and optical experiments, in the context of phase-shifting digital holography. Results show that a quantization to 4 bits is sufficient for an acceptable visual recognition, but 6 bits might be needed to reach visually lossless quality compared to the original reconstructed object. Furthermore, a lower bit depth of 2 bits lead to severe distortions with the appearance of speckle noise.

Two non-uniform quantization methods are proposed in [11]. The companding approach combines the efficiency of uniform quantization with the improved performance of non-uniform quantization. More specifically, a non-linear transform is first applied to the data, followed by a uniform quantizer. Rather than transforming the input data, a uniform sampling grid is non-linearly transformed such that the grid is dense where the data is compact and sparse otherwise. For this purpose, two companding grids are introduced, based on diamond and logarithmic spiral patterns respectively. Finally, lossless coding is applied on the quantized values. Similarly, the method in [12] first extracts clusters from the histogram of the real and imaginary data, or from the histogram of the amplitude and phase data, exploiting a priori knowledge of the data distribution. The hologram is then quantized using the resulting clusters centers.

A Multiple Description Coding (MDC) scheme is proposed in [13] using quantization. The scheme is processing amplitude and phase information independently. More precisely, the probability density distribution of the source is first computed. Two descriptions are then generated, where each description is quantized using a codebook obtained by the k-means algorithm. At the receiver side, decoding is performed using Maximum-A-Posteriori (MAP). The proposed MDC scheme is shown to be efficient in case of transmission over a channel with Additive White Gaussian Noise (AWGN).

In [14], Vector Quantization (VQ) is proposed and compared to Scalar Quantization (SQ) for different holographic data representations. It is shown that an intensity-based representation is better suited in the case of VQ. In contrast, the amplitude-phase representation is more suited for SQ than for VQ, due to the decorrelation between amplitude and phase information.

3.2. Transform-based holographic data compression

Transform coding is widely used for image compression, due to its efficient decorrelation and thus its ability to compact the signal energy into a few significant transformed coefficients. For instance, the JPEG image coding standard [15] relies on a Discrete Cosine Transform (DCT), whereas the JPEG 2000 standard [16] uses a Discrete Wavelet Transform (DWT). Therefore, quite naturally, researchers have explored the application of transform coding for holographic data compression.

In [9], a DFT is applied on non-overlapping 8 x 8 blocks. In this way, the energy tends to be concentrated into a few DFT coefficients. Next, in each block, the *n* smallest DFT coefficients are set to zero, where *n* is a predefined value in the range [1, 64]. The remaining significant coefficients can then be encoded, for instance using a Huffman code or a run-length scheme. It is shown that 92% of the DFT coefficients can be discarded with a minimal loss.

A wavelet analysis is introduced in [17] for the compression of digital holograms. More specifically, 1D-DWT is applied on the complex-valued data. Wavelet coefficients whose value is smaller than a threshold are set to zero. In turn, remaining significant coefficients are uniformly quantized and lossless encoded. It is shown that the proposed wavelet scheme is superior to a simple uniform quantization. It is also observed that among the wavelet functions tested, none consistently outperforms the other ones, and that on average the best performance is obtained for 3 levels of decomposition.

Wavelets are efficient for piecewise smooth signals, such as natural images. Consequently, they have been successfully applied for image compression. However, holograms have very different characteristics. In particular, object features, such as edges, are typically spread out in the hologram. Hence, directly applying wavelets to the hologram typically leads to poor performances. Taking into account the above considerations, a new class of wavelets – Fresnelets – is proposed in [18] especially designed for digital holography. More specifically, Fresnelets are obtained by applying the Fresnel transform to B-Splines [19]. Properties of the Fresnel transform, particularly translation and dilation, are studied. Moreover, a Heisenberg-like uncertainty relation is derived giving a bound on the spatial spreading in the Fresnel domain.

In [20], Fresnelets are used in PSI digital holography for compression. More precisely, the complex wavefront is decomposed to Fresnelet coefficients. Two schemes are then proposed. The first one simply applies uniform quantization on the Fresnelet coefficients, followed by Burrows-Wheeler transform (BWT) lossless coding. The second one is based on Set Partitioning In Hierarchical Trees (SPIHT). Performance assessment is carried out by performing quantitative measurements on the reconstructed object image. It demonstrates that Fresnelets can successfully be applied in PSI and leads to efficient compression.

In [21], the authors consider viewpoint scalability. In this context, an efficient wavelet should allow coefficient pruning, to transmit only data relevant for a given viewpoint. However, it is shown that Fresnelets lack good localization in frequency, hence preventing this viewpoint-based adaptation. Conversely, the authors propose Gabor wavelets, which have better time-frequency localization, and are therefore more adapted for the proposed view-dependent approach. For reconstruction, the Angular Spectrum method is used. Experimental results show that Gabor wavelets effectively suppress the unwanted orders created in the reconstruction for off-axis holograms and have better time-frequency localization for view-dependent compression techniques. However, the Gabor basis functions have two limitations: they fail to fulfil the admissibility condition and they entail unequal sizes of the sinusoids for various frequencies. To address these two weaknesses, in a subsequent work [22], they propose to use Morlet wavelets, which are derived from Gabor basis functions. An efficient discretization scheme is also described for view-dependent representation. The paper concludes that view-dependent representation in conjunction with Morlet wavelets is promising for next generation 3DTV applications.

3.3. Standard-based holographic data compression

The use of existing image and video coding standards to compress holographic data has also been investigated.

In [23], JPEG [15] and JPEG 2000 [16] are applied to compress interference patterns in phase-shifting interferometry. Both methods are shown to be effective, achieving compression ratios of 20 and 27, for JPEG and JPEG 2000 respectively, while maintaining a good quality of the reconstructed object.

A digital hologram video is captured from a moving 3D object in [24]. Fringe patterns are divided into blocks, referred to as segments. These segments undergo a 2D DCT and are rearranged into a video sequence by means of a 3D scanning. Finally, the resulting video sequence is encoded using the H.264/AVC video coding standard [25]. The authors show the effectiveness of the scheme, and claim significantly improved compression performance when compared to earlier works.

In [26], the use of MPEG-4 [27] (Advance Simple Profile) is investigated to encode hologram sequences. The scheme is shown to be effective, although it has been designed for conventional video, achieving good reconstruction quality with compression ratios of 20. The authors also show that inter-frame coding outperforms intra-frame coding. In other words, the scheme is capable to exploit temporal redundancies in the hologram sequences. Similarly, in [28], the authors study and compare two video coding schemes, H.264/AVC [25] and the wavelet-based Dirac [29]. Performance is assessed in terms of Normalized Root Mean Square (NRMS) and with subjective experiments. In the latter case, the observers are successively shown two sequences, the uncompressed reference and one compressed version, in random order. Then, they have to indicate the compressed one. The bitrate of the compressed sequence is varied until the threshold of visually lossless quality is found. The results show that performance is content-dependent. Compression ratios up to 4 to 7.5 can be achieved with visually lossless reconstruction quality.

The authors in [30] investigate the performance of the recent H.265/HEVC state-of-the-art video coding standard [31] to compress hologram sequences obtained from animated virtual objects with phase-shifting holography. It is shown that high reconstruction quality can be obtained with a bit rate of 15 Mbps. A comparison with H.264/AVC [25] is also made, demonstrating the superiority of H.265/HEVC in this context. Similarly in [32], it is reported that H.265/HEVC provides competitive subjective quality when configured in intra-frame coding mode for holographic images.

3.3.1. JPEG 2000-based with arbitrary packet decomposition and directional wavelet transforms

JPEG 2000 (ISO/IEC 15444-1 ITU-T Rec. T.800) [16] has proven to be a very versatile and powerful coding engine. Though JPEG 2000 was originally designed to replace JPEG in photography products, it has – due to the major success of JPEG – mainly been deployed in the professional marketplace. Illustrative are its successful integration in digital cinema and broadcasting environments, medical imaging, surveillance, cultural heritage archives etc.

The coding architecture of JPEG 2000 is built around two main components: a wavelet transform module and a powerful bit modeling and entropy coding engine. The core standard (Part 1) supports two wavelet transforms based on the lossy, floating-point CDF 9/7 transform kernel and the lossless integer 5/3 transform kernel. It also supports the classical Mallat wavelet decomposition style, well suited for classical natural images. The subsequent bit modeling and entropy coding unit, namely Embedded Block Coding by Optimized Truncation (EBCOT), first subdivides the wavelet transformed image in code blocks, which can have arbitrary dyadic dimensions. These code blocks are individually encoded by processing them in bitplane-by-bitplane fashion with multiple passes per bitplane – i.e. the bit modeling step – and subsequently entropy encoded utilizing context-based adaptive binary arithmetic encoding. This process results in a collections of embedded bitstreams that can be attributed to a specific quality and resolution level, and moreover facilitate random spatial access to the dataset. The latter is not unimportant in a holography context if information related to, for instance, a particular viewing angle (range) needs to be retrieved. Depending on the requirements imposed on the final codestream, these elementary, embedded bitstreams are reordered and recombined to support the desired quality and resolution scalability levels while deploying a Langrangian-based rate-distortion optimization system to target a particular bitrate or decoding quality.

The versatility of the JPEG 2000 encoding architecture lies exactly in its flexibility in combining arbitrary transform decomposition styles and transform kernels with the powerful EBCOT unit. Hence, this architecture is an evident choice if one wants to investigate and tune coding technology for handling holographic data.

As indicated already, holographic data is characterized by significantly larger amount of high-frequency content, where natural images typically depict a $1/f^2$ power spectrum distribution. Moreover, the fringe patterns possess a significant directionality. Hence, it is evident to attempt to build a coding architecture that exploits these characteristics. Tackling the higher spatial frequency content can be done by deploying packet decompositions that are – in contradiction to the Mallat decomposition – not only further decomposing the low-frequency subbands but also decompose the higher-frequency subbands to facilitate more energy compaction. JPEG 2000 Part 2 (ISO/IEC 15444-2 ITU-T Rec. T.801) supports such packet decompositions, unfortunately the standard does not support a homogeneous decomposition style when the number of wavelet levels increases. Hence, in [33][34] a JPEG 2000 architecture compliant decomposition mechanism was proposed to enable fully this tool.

Furthermore, exploiting directionality appears to be worthwhile as well. In [33][34] the authors propose to replace the classical JPEG 2000 wavelet transform by a direction-adaptive wavelet transform – allowing the above introduced packet decompositions as well – that enables the use of direction-adaptive wavelet filters introduced by Chang et al. [35].

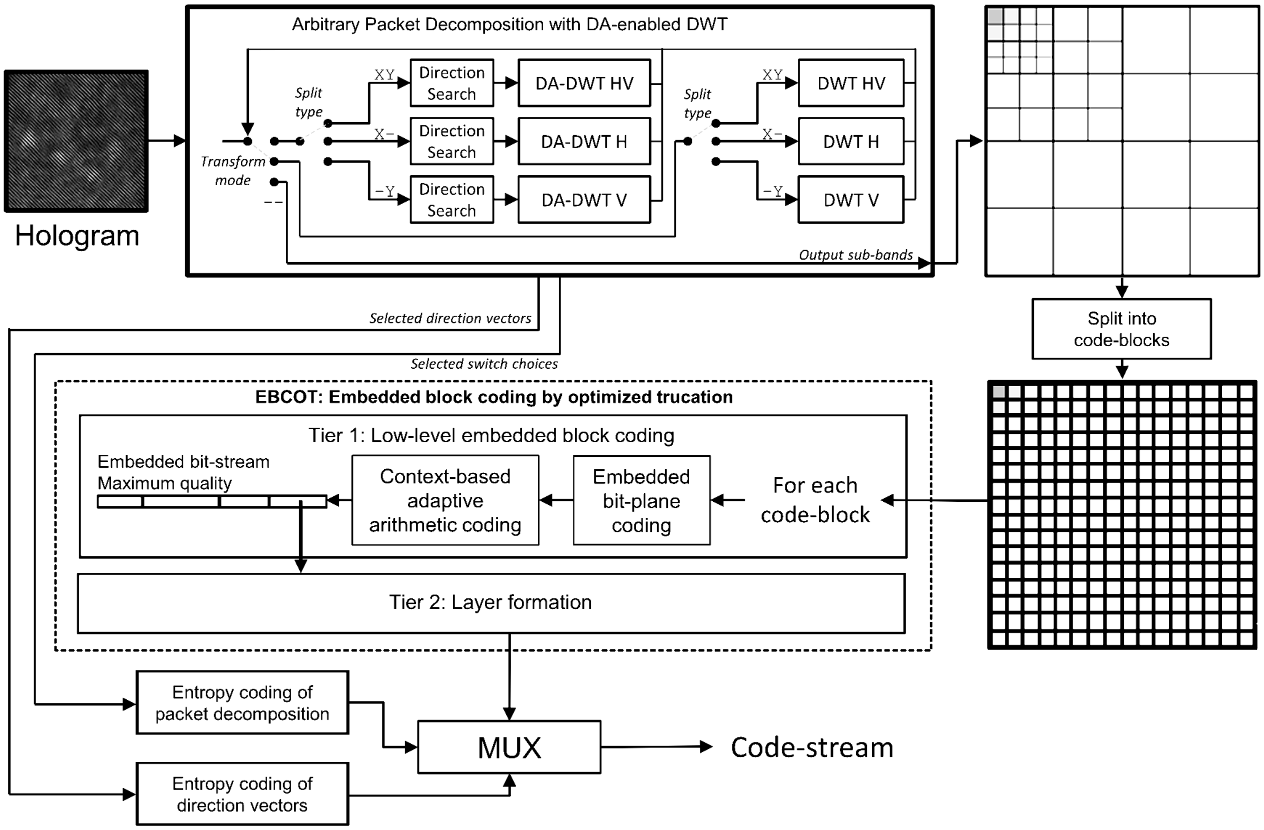

Figure 2 – JPEG 2000 architecture extended with an arbitrary packet decomposition and direction-adaptive discrete wavelet transform [34].

Significant improvements in coding performance were reported for off-axis holography and computer-generated holography relative to the conventional JPEG 2000 standard, with Bjøntegaard delta-peak signal-to-noise ratio improvements ranging up to 11 dB for lossy compression in the 0.125 to 2.00 bpp range and bit-rate reductions of up to 1.6 bpp for lossless compression [34][36]. Hence, these results illustrate the versatility and rate-distortion performance of JPEG 2000 based architectures, combined with a rich set of functionalities, as will be illustrated in the next section as well.

3.3.2. JPEG 2000-based with separable and non-separable vector lifting schemes

Considering more specifically the problem of phase-shifting holography, a JPEG 2000-based adaptive vector lifting scheme is proposed in [8]. More specifically, the paper considers the encoding of the shifted distance representation $D^{(1)}$ and $D^{(2)}$ as introduced in Eq. (6), but it can also effectively be used with intensity of the interference patterns. Observing that these different channels show some redundancies, a multiscale decomposition based on a separable Vector Lifting

Scheme (referred to as SEP-VLS hereafter) is defined, as illustrated in Figure 3. The resulting coefficients are then encoded using EBCOT. A gain of about 2 dB and 0.15 in terms of PSNR and SSIM, respectively is reported, when compared to an independent coding.

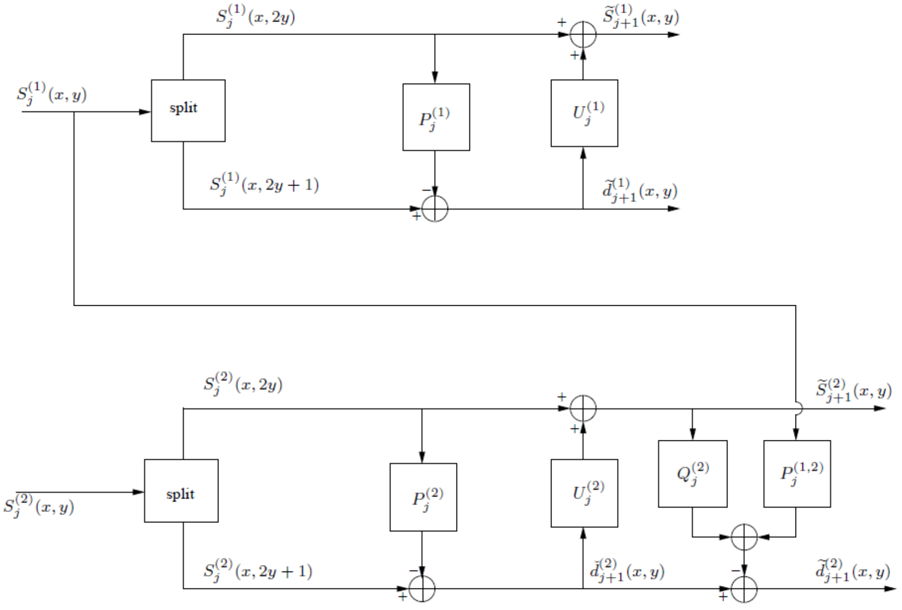

Figure 3 – Separable Vector Lifting Scheme [8].

Nevertheless, it can be observed that the data to be encoded presents some two dimensional isotropic characteristics. In order to better cope with these visual patterns, a non-separable adaptive VLS-based decomposition (denoted as NS-VLS hereafter) is introduced in [37]. In this way, the correlation between the two channels, as well as their 2D wave characteristics, can be simultaneously exploited. Moreover, the impact of using longer lengths of the prediction lifting operator is also investigated. For this purpose, the prediction filter coefficients are optimized by minimizing the variance of the detail signal in order to reduce the complexity of the proposed decomposition.

With these characteristics, the proposed NS-VLS-based decomposition is well suited for phase-shifting holograms. For a prediction filter length of 2, NS-VLS outperforms SEP-VLS by up to 10% in terms of bitrate, and 0.8 dB in terms of PSNR of the reconstructed object. Moreover, longer prediction filters may lead to further improvements. For instance, NS-VLS with a filter length of 12 achieves a significant gain that reaches 80%, 12 dB and 0.29 in terms of bitrate saving, PSNR and SSIM respectively, when compared to NS-VLS with a filter length of 2.

4. CONCLUDING REMARKS, OPEN ISSUES, AND PERSPECTIVES

Due to its high potential in several applications, digital holography is attracting significant interest. In this context, one important challenge is to be able to find an efficient and compact representation to code holographic information. As we have seen in this overview, several research groups worldwide have proposed innovative solutions.

Despite the progress made in recent years, more work is needed in order to realize the vision of digital holography as the ultimate 3D experience. However, among other factors, the multidisciplinary nature of the topic, involving optics and signal processing, makes the problem more challenging. In particular, further investigations are needed in several directions:

- Digital holograms can be produced in different settings, e.g. on-axis versus off-axis, using digital recording or CHG. The process also includes different parameters, such as the hologram dimensions, the pixel size, or the wavelength. All these design choices may influence the characteristics of the holograms, which in turn may impact the subsequent coding techniques. Comprehensive experiments on a wider parameter space are needed in order to better understand these dependencies.

- Most of the current state-of-the-art techniques have essentially considered very simplistic objects. Indeed, current technology only allows capturing objects or scenes with small angular size. In order to move ahead, more complex scenes have also to be tackled, corresponding to more realistic application scenarios.
- It is currently very difficult to compare results presented in different papers. To alleviate this issue, a better quality assessment methodology, including common open databases, is needed. An open access database for experimental validations of holographic compression engines is introduced in [36]. It currently includes a dataset of 5 computer-generated holograms. More specifically, three data representations are available: intensity interference patterns, complex wavefields, and phase-only holograms. It is intended that this database will be enhanced with more types of holographic content in the future. This is a notable contribution in order to enable researchers to meaningfully compare different coding techniques on a common dataset.
- Finally, another difficulty lies in the lack of reliable quality assessment measures. Previous papers have mainly applied objective quality measures designed for images, such as PSNR or SSIM. However, given the different nature and characteristics of holograms when compared to images, the use of these measures is not validated and justified. Moreover, subjective experiments are also needed to better understand the perceptual aspects related to the viewing of holograms [32]. This, in turn, would enable the development and validation of objective measures suitable for this type of content. In this context, it is worthwhile to refer as well to Finke *et al*. [38] which provides an excellent insight in visual perception aspects related to holographic displays.

Another open issue is at which stage the compression needs to take place. Related works in the literature have essentially considered the compression and transmission of holograms. However, an alternative is also possible, namely to transmit a conventional representation of the 3D scene, and to compute the hologram at the display end. This approach offers two advantages. First, existing 3D video coding techniques can be applied, without the need to define new coding solutions especially designed for holograms. Second, this scheme allows for a full decoupling between the representation of the scene and the display device. In [39], a holographic TV system is proposed based on multi-view video coding and depth map coding. The holograms are then generated at the receiver side. The authors claim to use 1/97000 of the data rate when compared to the transmission of hologram data, for the same subjective quality.

Given the emergence of new imaging technologies, the JPEG standardization committee has recently launch a new activity referred to as JPEG PLENO [40] (checkout www.jpeg.org for more information). It is targeting a new standard framework to represent and exchange data including light-field, point cloud and holographic imaging. It also aims at defining new compression techniques for improved performance. This incipient standardization activity opens therefore new promising perspectives for a wider adoption and deployment of digital holography in the future.

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