Exact Compensation of Rotational Motion for Holographic Video Compression

Kizhakkumkara Muhamad, Raees; Symeonidou, Athanasia; Blinder, David; Birnbaum, Tobias; Schretter, Colas; Schelkens, Peter

Published in:
Digital Holography and Three-Dimensional Imaging 2019

DOI:
10.1364/DH.2019.Tu4A.2

Publication date:
2019

License:
CC BY

Document Version:
Final published version

Citation for published version (APA):
Exact Compensation of Rotational Motion for Holographic Video Compression

Raees Kizhakkumkara Muhamad,1,2,* Athanasia Symeonidou1,2 David Blinder,1,2 Tobias Birnbaum,1,2 Colas Schretter1,2 and Peter Schelkens1,2
1 Vrije Universiteit Brussel, ETRO Dept., Pleinlaan 2, B-1050 Brussels, Belgium;
2 imec, Kapeldreef 75, B-3001 Leuven, Belgium
* Corresponding author: kraees@etrovub.be

Abstract: Holographic video imposes impractical bitrates for storage and communication without compression. We introduce exact motion compensation in a codec using rotational transformation of angular spectrum and obtain SNR improvements of 20 dB over HEVC.

1. Introduction

Implementing holographic display pipelines for video with an acceptable field of view is challenging due to the Gigapixel resolutions required coupled with the poor performance of traditional video compression codecs on holographic data. A framework for tackling video compression where ground truth knowledge about the scene was introduced in prior works [1]. The hologram of the current frame is segmented into individual contributions from different objects in the scene, and a motion compensation algorithm is applied on each object to predict the next frame. In this work we introduce a motion compensation algorithm that is analytically accurate. However, additional information has to be stored due to the finite size and discrete nature of digital holograms which is identified using short-time Fourier transform (STFT).

2. Motion Compensation

Rigid body motion is described by using a sequence of rotations $(\theta_x, \theta_y, \theta_z)$ around a pivot point $(x_o, y_o, z_o)$ followed by translations $(x, y, z)$. To predict changes due to this motion, we perform the relative motion on the hologram domain. The hologram of the current frame $g(x, y) = \mathcal{F}^{-1}(G(u, v))$ is used to compute the hologram at a parallel plane using the angular spectrum method such that the origin of the translated hologram and the pivot point are the same, where $H(u, v; z_o)$ is the transfer function of free space propagation between parallel planes. Thus we start from the Fourier transformed hologram

$$ G_1 \equiv G_1(u, v) = G(u, v)e^{i2\pi(a_{x_o}+y_o)}H(u, v; z_o). \quad (1) $$

The rotational transformation of angular spectrum method is used for formulating the propagation between non parallel planes sharing the same origin [2]. We use it to perform the same relative rotation motion which is described by the rotation matrix

$$ R(-\theta_x, -\theta_y, -\theta_z) = \begin{bmatrix} a_1 & a_4 & a_7 \\ a_2 & a_5 & a_8 \\ a_3 & a_6 & a_9 \end{bmatrix}, \quad (2) $$

giving us the intermediate transformed hologram $G_2 \equiv G_2(u, v) = G_1(\alpha(u, v), \beta(u, v))|J(u, v)|$ with

$$ \alpha(u, v) = a_1u + a_2v + a_3w(u, v), \quad \beta(u, v) = a_4u + a_5v + a_6w(u, v), \quad w(u, v) = \sqrt{\lambda^2 - u^2 - v^2}, \quad J(u, v) = (a_2a_6 - a_3a_5)\frac{u}{w(u, v)} + (a_3a_4 - a_1a_6)\frac{v}{w(u, v)} + (a_1a_5 - a_2a_4). \quad (3) $$

The final hologram $G_{mc} \equiv G_{mc}(u, v)$ is obtained by using $G_2$ to compute the hologram at the parallel plane having origin $(-x_f, -y_f, -z_f)$ which implies a translation of $(-x_f - x_o, -y_f - y_o, -z_f - z_o)$, thus we have all together

$$ G_{mc} = G(\alpha(u, v), \beta(u, v))H(u, v; -z_f - z_o)H(\alpha(u, v), \beta(u, v); z_o)|J(u, v)|e^{-i2\pi(x_fu+y_fv-x_o\alpha(u,v)-y_o\beta(u,v)-z_o)}. \quad (4) $$

The effect of applying motion compensation for rotations and translations in the spatial domain of a hologram of fixed size is shown in Fig. 1. The information outside the central crop is discarded while the missing information...
needs to be signalled. The rotational transformation of angular spectrum method rigorously satisfies the Helmholtz equation [2]. However for implementation in a digital system, the fast Fourier transform that is defined for an equidistant sampled grid cannot be directly applied to Eq. 4 due to the non-linear nature of the frequency sampling in Eq. 3, unless we apply interpolation. Interpolation causes errors that depends on the frequency grid warping [2]. Errors are localized in space and frequency and we use STFT with rectangular windows for identifying and re-signalling these neighbourhoods from the ground truth.

The motion compensated hologram of size $A \times B$ is divided into uniformly sized sub-holograms $g_{smc}^{k,l}[x,y]$ of size $N_u \times N_v$. The 2D-discrete Fourier transform of these sub-holograms is divided into uniformly sized blocks of size $N_u \times N_v$ which are denoted as space frequency blocks $G_{smc}^{k,l,i,j}[u,v]$, or SFBs for short:

$$
g_{smc}^{k,l}[x,y] = g_{mc}[(k-1)N_u + x, (l-1)N_v + y] \quad G_{smc}^{k,l,i,j}[u,v] = G_{mc}^{k,l}(i-1)N_u + u, (j-1)N_v + v$$

$$1 \leq x \leq N_u, 1 \leq y \leq N_v, 1 \leq k \leq \frac{A}{N_u}, 1 \leq l \leq \frac{B}{N_v}$$

$$1 \leq u \leq N_u, 1 \leq v \leq N_v, 1 \leq i < \frac{N_u}{N_u}, 1 \leq j < \frac{N_v}{N_v}$$

(5)

The same operations are done for the ground truth frame to obtain $G_{gt}^{k,l,i,j}[u,v]$. The decision metric $D[k,l,i,j]$ computes the mean squared error (MSE) between corresponding SFB’s and is used to identify which SFB’s to re-signal. The metric is motivated by the orthonormal nature of the DFT transform which implies the MSE between the global holograms will be $\sum_{k=1}^{N_u} \sum_{l=1}^{N_v} \sum_{i=1}^{\frac{N_u}{N_u}} \sum_{j=1}^{\frac{N_v}{N_v}} D[k,l,i,j]$. We apply uniform quantization on the SFB’s that are chosen in the decreasing order of $D[k,l,i,j]$ and include an overhead to signal their locations.

3. Results and Conclusions

We test the rate-distortion performance of a holographic video encoder/decoder system by applying the rigorous spherical wave propagation equation [1] on a point cloud object undergoing a rotation of $30^\circ$ around the vertical axis to generate holograms of size $4096 \times 4096$ and a pixel pitch of 1 µm at 30 frames/s. The distortion measure used is the peak signal to noise ratio (PSNR) calculated on the reconstructed absolute valued hologram in the object plane. Results shown in Fig. 1 indicates a significant BD-PSNR gain of 20 dB for the rate region from 0.25 to 2 bpp, over standard video and still image codecs. Techniques for segmenting holograms into contributions of individual objects needs to be investigated for extending this method to general scenes with multiple objects.

Acknowledgements

This work was funded by the European Research Council under the EU’s 7th Framework Programme (FP7/2007-2013) ERC Grant Agreement N. 617779 (INTERFERE). The Venus model is courtesy of Direct Dimensions Inc.

References