Evaluation of the compressibility of Computer-Generated Holograms

W. Pimenta[†][1] and L. P. Santos[1]

[1]Laboratório de Computação Gráfica, Departamento de Informática, Universidade do Minho, Braga, Portugal

---

Abstract

We present a preliminary investigation of the compressibility of Physically-Based Computer-Generated Holograms (PB CGHs) as represented in various bases. The goal is to identify which bases, if any, are suitable for applying the principles of Compressed Sensing (CS) to the generation of PB CGHs.
The Fourier, DCT and Haar wavelet bases were selected, as a representative sample of the time-frequency spectrum of representation bases, and evaluated according to several quality metrics.
Contrary to what previous research suggested, we found that the DCT basis, not the Haar wavelet one, in general yielded better results.

Categories and Subject Descriptors (according to ACM CCS): E.4 [Coding and Information Theory]: Data compaction and compression— I.4.2 [Compression (coding)]: Approximate methods— G.1.2 [Approximation]: Fast Fourier transforms (FFT)—Wavelets and fractals

---

1. Introduction

Physically-Based Computer-Generated Holography (PB CGH), although capable of emulating realistic 3D perception, involves extremely high sampling rates and computationally taxing generation algorithms, which make its use impractical. A possible path to overcome these issues is using Compressed Sensing (CS), which provides a way to reduce the sampling rates below the Nyquist frequency limit without loss of information, as long as the signal is captured in a basis where its representation is sparse (i.e. has many zero or near-zero coefficients)

The present work is a preliminary study towards using CS to alleviate the sampling requirements in the digital synthesis of holograms, particularly the physically-based method for creating CGHs (PB CGH). This would allow using the actual interference pattern generated by a point-cloud decomposition of the object or scene, rather than approximate representations (such as 2D images portraying depth slices of such scenes) which have been prevalent in previous CGH research, including its blending with CS [RSR11], due to the difficulties mentioned in the first paragraph. Naturally, a successful CS-based PB CGH pipeline will depend on whether such holograms are indeed compressible (sparse in appropriate bases), in which case the sampling requirements will be drastically reduced. It is finding such bases, if they exist, that constitutes the main motivation for this work.

2. Methodology

Because we're interested in the final reconstructions rather than in the holograms themselves, we can't rely solely on measuring the sparsity in the hologram using common [HR09] or novel [OAAF09] sparsity measures, but must also verify how much the compression of the hologram in a given basis affects the resulting image. The evaluation has thus been a two-step process, as described below.

Firstly, to identify which basis might provide a sparse representation for wave interference patterns, a set of bases was selected, specifically, the Fourier (DFT) and cosine (DCT) bases (pure-frequency) as well as the Haar wavelet basis, which offers a compromise between time and frequency resolution. Holograms were generated from 15 different point-cloud 3D models, with sizes ranging from 3 points to 42 744 points, using the standard (exhaustive sampling) PB CGH method, and converting them to the bases under consider-

---

[†] This work has been funded by FCT – Fundação para a Ciência e a Tecnologia, through the grant SFRH/BD/74970/2010

DOI: 10.2312/egp.20151042

ation. Then, coefficients in those bases were gradually removed (in ten steps, scaled logarithmically, with the highest level corresponding to removing 99.5% of them), from the least to the most expressive ones.

In a second step, the resulting representations were converted back to the canonical basis, resulting in lossy-compressed versions of the original holograms, which were then digitally propagated to form an image given an ideal observer position (see Figure 1). The error in both the holograms (step 1) and the reconstruction images (step 2), compared to the original holograms and the images reconstructed from them, was measured using various quality metrics, for every 3D model and every data reduction level.

3. Results

Despite several studies having chosen Haar wavelets for CGH, [RSJ10] we found that the results were on average poorer than when the Fourier or cosine transforms were used. As Figure 2 shows, on average the holograms compressed in the Haar basis underperformed compared to the others, although they got close to those using Fourier-based compression, particularly in the higher compression levels.

The basis that consistently exhibited the best results across the board was the cosine transform (DCT). This suggests that the bases that emphasise the sparsity in PB CGHs likely have similar properties to the DCT.

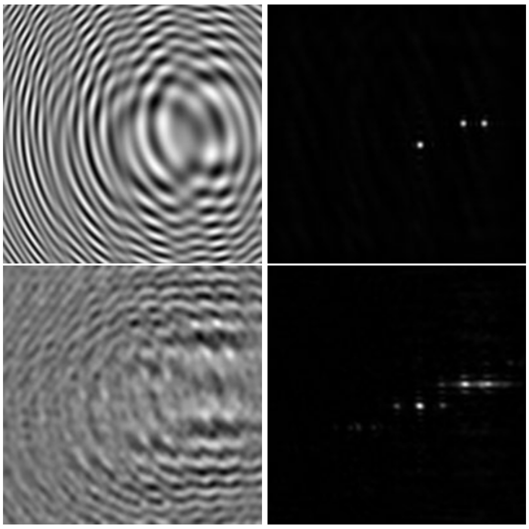

Figure 1: Sample of the data used. The top row corresponds to one of the original holograms (the simplest of the tested scenes, consisting of 3 point light sources) and its digital reconstruction as an image. The bottom row is the same hologram with 99.5% of coefficients removed in the Fourier basis (the highest level of compression analyzed in this study) and its image reconstruction.

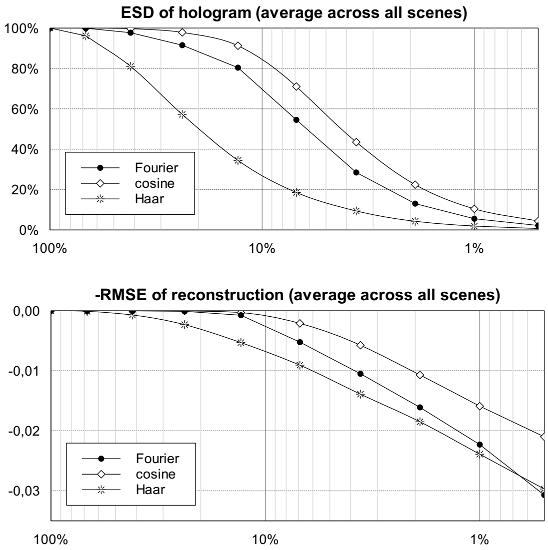

Figure 2: Some of the metrics collected to indicate the ability of each basis to preserve information in the signal: Energy Spectral Density (ESD) of the transformed holograms, as a proxy for sparsity –how concentrated is the energy in the coefficients of the basis– and Root Mean Square Error (RMSE) of the images, both plotted against the decreasing number of coefficients preserved.

4. Conclusions

We have identified the DCT as a basis where holographic content is compressible, and thus a strong candidate for applying CS to the PB CGH pipeline.

It is still necessary to ensure that this transformation (or others with similar properties) is suitably incoherent with the point sampling (Kronecker) basis, which is unavoidable given the digital nature of the hologram synthesis process (i.e, we can't directly collect multiplexed measurements). Once such an appropriate basis is obtained, the next step will be to calculate the fraction of samples required given its incoherence value, and to assess potential performance gains compared to classical, non-compressive approaches.

References

[HR09] HURLEY N., RICKARD S.: Comparing measures of sparsity. *IEEE Trans. on Inf. Theory 55*, 10 (2009), 4723–4741. 1

[OAAF09] ODEJIDE O., AKUJUOBI C., ANNAMALAI A., FUDGE G.: Determination of best sparsifying basis for compressive sampling. *Int'l Rev. of Electrical Eng. 4*, 2 (2009). 1

[RSJ10] RIVENSON Y., STERN A., JAVIDI B.: Compressive fresnel holography. *Journal of Disp. Tech. 6*, 10 (2010), 506–509. 2

[RSR11] RIVENSON Y., STERN A., ROSEN J.: Compressive multiple view projection incoherent holography. *Optics express 19*, 7 (2011), 6109–6118. 1