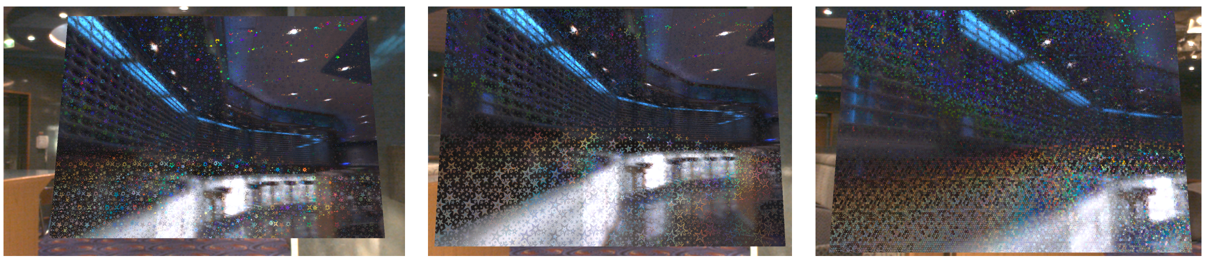
# Practical acquisition and rendering of common spatially varying holographic surfaces

Antoine Toisoul
Department of Computing
Imperial College London
ast13@imperial.ac.uk

Daljit Singh J. Dhillon
Department of Computing
Imperial College London
d.dhillon@imperial.ac.uk

Abhijeet Ghosh
Department of Computing
Imperial College London
ghosh@imperial.ac.uk



(a) (b) (c)

**Figure 1: Real-time renderings of several holographic surfaces in the bar environment. (a) Holographic paper with star pattern. (b) Star pattern with gradients inside the stars. (c) Holographic gift bag with circles.**

## ABSTRACT

We present a novel approach to measure the appearance of commonly found spatially varying holographic surfaces. Such surfaces are made of one dimensional diffraction gratings that vary in orientations and periodicities over a sample to create impressive visual effects. Our method is able to recover the orientation and periodicity maps simply using a flash illumination and a DSLR camera. We present real-time renderings under environmental illumination using the measured maps that match the observed appearance.

## CCS CONCEPTS

• **Computing methodologies → Real-time simulation**; *Reflectance modeling*;

## KEYWORDS

diffraction, wave optics, real-time rendering

**ACM Reference Format:**

Antoine Toisoul, Daljit Singh J. Dhillon, and Abhijeet Ghosh. 2018. Practical acquisition and rendering of common spatially varying holographic surfaces. In *Proceedings of SIGGRAPH '18 Posters.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3230744.3230815



*SIGGRAPH '18 Posters, August 12-16, 2018, Vancouver, BC, Canada*



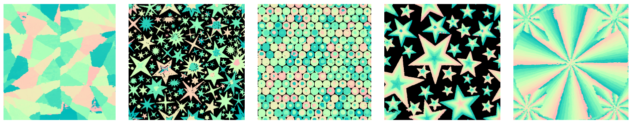
ACM ISBN 978-1-4503-5817-0/18/08.
https://doi.org/10.1145/3230744.3230815

## 1 INTRODUCTION

Spatially varying holographic surfaces are very common with modern manufacturing techniques but have never been rendered realistically in computer graphics due to the measurement and computational challenge they represent. Such surfaces are made of diffraction gratings (nanogeometry) that disperse white light into its main component hence creating visually pleasing rainbow effects on the surface. Recent work on diffraction in computer graphics [3], focused on the acquisition and rendering of diffraction effects on homogeneous surfaces and on which the diffraction pattern can be entirely photographed. These two assumptions do not hold in the case of holographic surfaces. In this work we focus on a specific type of holographic surface, that is made of one dimensional diffraction gratings. These gratings vary in orientation and periodicity over the entire sample to produce impressive visual effects. Although very simple, such a model is well known to produce a wide range of diffraction effects such as gradients and kinematic effects. Our method is able to measure the orientations and periodicities in order to reproduce these effects photo realistically and in real-time using the method of [4]. We also provide the first database of measured maps for holographic surface rendering.

## 2 RENDERING MODEL

We model a holographic surface with sinusoidal diffraction gratings. For a grating aligned with the x axis, the height field variation is given by $h(x, y) = \frac{h_0}{2}(1 + cos(2\pi \frac{x}{a}))$ where $a$ is the periodicity of the grating. The goal is to recover the periodicity $a$ as well as the orientation. For rendering, we use Dhillon et al.'s [1] reformulation of Stam's Bidirectional Reflectance Distribution Function (BRDF) [2]. In this model, a Taylor expansion is applied to Stam's BRDF. In the case of a sinusoidal grating, a second order approximation is enough to get accurate first and second order diffraction lobes,



(a) (b) (c) (d) (e)

**Figure 2: Tangent maps measured with the flash illumination method (maps encoded as RGB = XYZ). (a) Polygonal holographic paper. (b) Holographic gift bag with a star pattern. (c) Holographic gift bag with circles. (d) Holographic paper with gradient variations inside the stars. (e) Holographic paper with a kinematic effect.**

leading to the following formulation of the BRDF :

$$f_r(\omega_i, \omega_o, \lambda) = C(\omega_i, \omega_o)(I_0(u,v) + w^2 I_2(u,v) + w^4 I_4(u,v)) \quad (1)$$

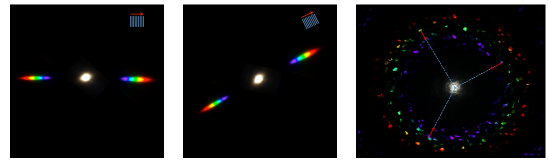
with $C(\omega_i, \omega_o) = \frac{F^2 G}{F_0^2 w^2}$ where F is the Fresnel factor, G the geometric factor and the non normalized half vector has coordinates $\vec{h} = (u, v, w)$. For the calculation of the lookup tables $I_0$, $I_2$ and $I_4$, please refer [1]. The final BRDF expression is a rather complex equation that is a linear combination of five Gaussian lobes located at $(0, 0)$ for the specular highlight, $(\pm\frac{\lambda}{a}, 0)$ for the first order of diffraction and $(\pm\frac{2\lambda}{a}, 0)$ for the second order of diffraction where $\lambda$ is the diffracted wavelength.

## 3 FLASH ILLUMINATION MEASUREMENT

Our measurement setup requires a camera (we used a Canon 650D) and a flash illumination (here an iPhone 5S torchlight). We capture HDR photographs of the holographic surface illuminated with the flash illumination. The distance between the light source and the sample is chosen so that the entire diffraction is visible (see figure 3c). The goal is to obtain a set of pictures where every diffracted area on the surface diffracts light in at least one of the pictures. In practice one to six images were required depending on the complexity of the holographic pattern. Note that due to manufacturing costs, the holographic surfaces that we measured were made of an examplar tile that is repeated over the entire sample. We use homography transformations to align each repeated tile to the same frame of reference and then use the acquired data to recover the grating orientation and periodicity for the examplar tile using several observations of the same examplar tile.

### 3.1 Grating orientation

As shown in figure 3a and b, the diffraction pattern of a sinusoidal grating is aligned with the axis of the grating. Hence the orientation of the grating is simply given by the angle that the direction towards the specular highlight makes with the x axis. Note that knowing if we observe a positive or negative order of diffraction is not necessary as the grating orientation is the same modulo 180 degrees due to the symmetry of the sinusoid. As shown in figure 3c, we find each location that diffracts light using an intensity threshold and compute the local orientation of the grating. Results of the recovered examplar tiles are shown in figure 2.



(a) (b) (c)

**Figure 3: Computation of the grating orientation. (a, b) First order diffraction pattern of a dimensional sinusoidal grating. The grating and its direction are shown at the top-right. The pattern aligns with the orientation of the grating. (c) The local orientation of the diffraction grating at a diffracted pixel, is given by the direction towards the specular highlight (shown by the red vectors).**

### 3.2 Grating periodicity

Such a simple method can also be used to recover the grating periodicity at each location on the sample. Indeed, the distance between the specular highlight and an order of diffraction is related to the periodicity by $a = \frac{n\lambda}{|u|}$ where n is the order of observed diffraction and $u$ the projection of the non normalized half vector on the grating orientation. We add a spectral filter on the light source and use the camera and light distance to the sample to calculate $u$ over the entire image which allows to recover the periodicity. Renderings of the holographic surfaces under environmental illumination are shown in figure 1. We compute the spectral integration at runtime and reach 20 to 30 FPS with a NVIDIA 1080 GPU at 1080p resolution.

## 4 CONCLUSION

We presented a very simple method to acquire the appearance parameters of commonly found spatially varying holographic surfaces for real-time rendering. Such orientation and periodicity maps can be used to better understand how these holographic effects are made as well as creating new ones.

## ACKNOWLEDGMENTS

This work was supported by an EPSRC Early Career Fellowship EP/N006259/1, a Royal Society Wolfson Research Merit Award and a SNSF Early Postdoc .Mobility Fellowship P2BEP2_165343. We also thank EPSRC Centre for Doctoral Training in High Performance Embedded and Distributed Systems (HiPEDS, grant EP/L016796/1) and Mirri who provided us with samples of holographic papers.

## REFERENCES

D.S. Dhillon, J. Teyssier, M. Single, I. Gaponenko, M.C. Milinkovitch, and M. Zwicker. 2014. Interactive Diffraction from Biological Nanostructures. *Comput. Graph. Forum* 33, 8 (Dec. 2014), 177–188. DOI: http://dx.doi.org/10.1111/cgf.12425

Jos Stam. 1999. Diffraction Shaders. In *Proceedings of the 26th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH '99)*. ACM Press/Addison-Wesley Publishing Co., New York, NY, USA, 101–110. DOI: http://dx.doi.org/10.1145/311535.311546

Antoine Toisoul and Abhijeet Ghosh. 2017a. Practical Acquisition and Rendering of Diffraction Effects in Surface Reflectance. *ACM Trans. Graph.* 36, 5, Article 64c (July 2017). DOI: http://dx.doi.org/10.1145/3012001

Antoine Toisoul and Abhijeet Ghosh. 2017b. Real-time Rendering of Realistic Surface Diffraction with Low Rank Factorisation. In *Proceedings of the 14th European Conference on Visual Media Production (CVMP 2017) (CVMP 2017)*. ACM, New York, NY, USA, Article 2, 7 pages. DOI: http://dx.doi.org/10.1145/3150165.3150167