

# A Volumetric Approach to Visualize Holographic Reconstructions

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## Abstract

*In synthetic holography, the emphasis has been on numerical simulation methods for the recording and reconstruction processes, but methods to visualize the calculated results are yet underdeveloped. We show how volume slicing and volume rendering using a threshold for translucency can be applied to synthetic holography. Results of the three-dimensional visualization of the reconstruction are presented, thereby illustrating the usefulness of the threshold operator.*

**Keywords:** Scientific visualization, synthetic holography, reconstruction.

## 1 Introduction and motivation

In synthetic holography, a number of methods and tools for computing holograms and holographic images exist. These tools are commonly used for calculating the diffraction properties of holograms. The visualization of the reconstruction in depth is not the primary task of such programs, although two-dimensional reconstructions are usually performed. Tools specialized in visualizing three-dimensional holographic reconstructions are missing. In this work we describe such a tool and show that it allows a better spatial understanding of the holographic reconstruction and circumvents the time-consuming and material-wasting optical verification of synthetic holograms.

The reconstruction of a two-dimensional object like a thin plate which is parallel to the hologram plane appears sharp only at a distinct distance to the hologram. If this distance is known, a two-dimensional visualization is sufficient. The visualization of a three-dimensional object poses new challenges: parts of the object appear sharp at a specific distance where other parts appear blurred. To discover the shape of the reconstructed object, it is necessary to find the sharp parts and to visualize them in a three-dimensional view.

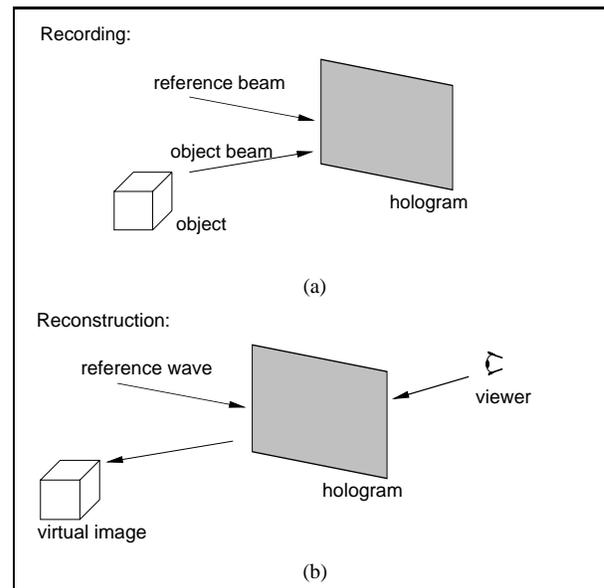
In this paper we approach the visualization of holographic reconstruction using three-dimensional volumetric methods. We will show that volume slicing helps to find

focus points and that volume rendering using a threshold operator for translucency exposes the shape of the object in three dimensions.

The paper is organized as follows: First, we briefly discuss optical and synthetic holography. Then we exemplify related work and explain our approach to simulate and visualize the hologram reconstruction. We discuss results and close with an outline of future work.

## 2 Optical and synthetical holography

Holography is a method for three-dimensional imaging of objects. Dennis Gabor presented holography for the first time in 1948 [5].



**Figure 1: Recording (a) and reconstruction (b)**

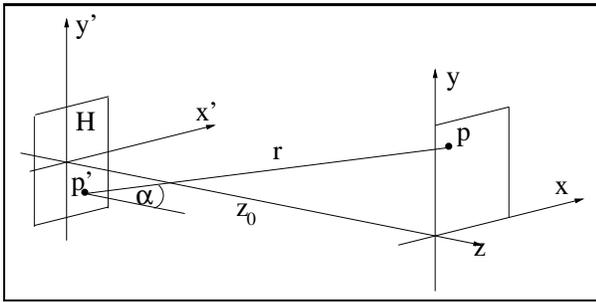
As illustrated in Figure 1 holography is a two-step process. In the recording step a coherent light wave is split in two beams. One beam illuminates the object to be imaged, the other beam — called reference wave — hits directly the holographic plate. The waves reflected by the object

are called object wave. The interference pattern of object wave and reference wave is recorded on the holographic plate and constitutes the hologram (see Figure 1(a)).

In the reconstruction step, the hologram (suitably processed) is illuminated with another reference wave. The reference wave is diffracted by the interference pattern of the hologram. Part of the diffracted wave is an identical copy of the object wave of the recorded object. Looking at the hologram, the viewer gets the impression of a three-dimensional object, the virtual image (Figure 1(b)).

In synthetic holography, the optical processes are (partially) replaced by numerical calculations performed by the computer.

To record a synthetic hologram, the object and the reference wave are described by their physical properties. For each object point the amplitude and phase of the emitted light is given in the form of a data set. With this description various methods for calculating the interference pattern of the hologram exist (e.g. [4] [10]). The computed hologram can either be transferred to a holographic film which is reconstructed optically in an experimental setup or be reconstructed synthetically.



**Figure 2: Presumed geometric relationship between object and hologram  $H$  for solving the Kirchhoff diffraction integral**

For synthetical reconstruction, the hologram is given as two-dimensional complex valued field. Additionally the parameters of the reference wave are given. The illumination of the hologram with the reference wave is simulated by evaluation of the Kirchhoff diffraction integral (cf. [7]),

$$U(p) = \frac{1}{i\lambda} \int_S u_0(p') \frac{\exp(ikr)}{r} \cos(\alpha) ds. \quad (1)$$

or its approximations (see Figure 2). Here,  $U(p)$  is the electric field strength at the point  $p$ .  $U(p)$  yields from the field strength  $u_0(p')$  contributed from each point  $p'$  of the hologram plate  $H$ ,  $\lambda$  is the wavelength,  $r$  the distance between  $p$  and  $p'$  and  $\alpha$  the angle between  $p' - p$  and the incident illumination wave. The intensity of  $U(p)$  constitutes the image of the reconstructed object.

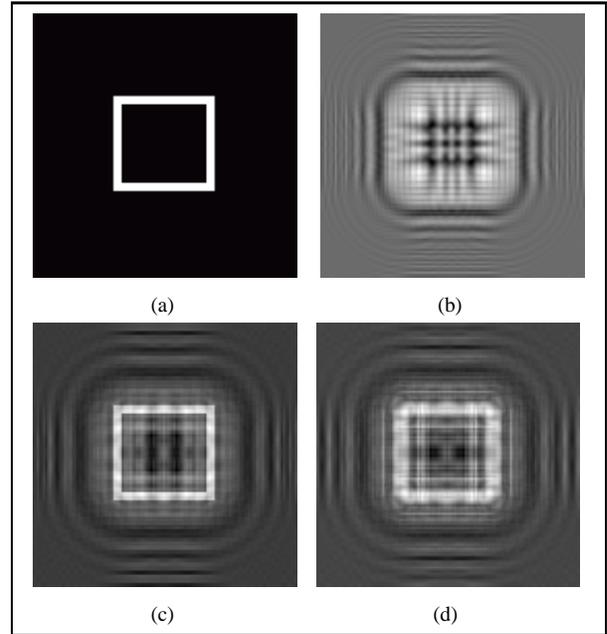
### 3 Related work

Programs like the optical cad system DigiOpt [1] and ImageH [12] compute two-dimensional visualizations of holographic reconstructions. This is done by calculating the amplitude and phase of each point  $p$  in a plane parallel to the hologram in distance  $z_0$  by evaluating Eq. 1. The intensity of each point in this plane results in an image.

If the hologram displays a two-dimensional object, this reconstructed object will focus only in a distinct depth which equals to the distance of the object at recording time. For all other distances the object will be blurred. Figure 3 shows a hologram and two images of reconstruction in different depths.

For three-dimensional objects recorded in the hologram, only the points belonging to the object will appear sharp in a reconstruction plane. Other tools developed for optical design are not much advanced.

For educational purposes, The Optics Project (TOP) points out the possibilities of three-dimensional visualization in optics [3]. TOP provides interactive visualization of fundamentals of optics, e.g. Fresnel diffraction of a single and a double slit, but provides no volume visualization of hologram reconstruction.



**Figure 3: Example of a two-dimensional visualization of hologram reconstruction: (a) original object (b) hologram, (c) sharp reconstruction focusing the object, and (d) blurred reconstruction**

## 4 Visualization of hologram reconstruction

The three-dimensional interactive visualization of the holographic reconstruction is performed by computing a volumetric data set; the difficulty to overcome, as indicated above, is the blurring effect. This is done by calculating a set of two-dimensional images parallel to the hologram using the Fresnel transform

$$U(x,y) = \frac{\exp(ikz)}{i\lambda z} \int \int_{-\infty}^{\infty} u_0(x',y') \times \exp\left(\frac{ik}{2z}((x-x')^2 + (y-y')^2)\right) dx' dy' \quad (2)$$

that approximates the Kirchhoff diffraction integral, where  $z$  runs from the chosen  $z_s$  to  $z_e$  in steps of length  $dz$ . These images are combined to form a volumetric data set (see Figure 4).

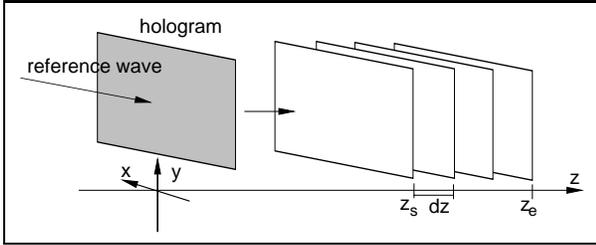


Figure 4: Calculation of the volumetric data set

The data set consists of scalar intensity values depending on their position in space. We normalize the data and map the intensities to 256 grey values. Various volume visualization techniques are applicable to the data space [9] [6]. To visualize the holographic reconstruction, we found volume slicing and volume rendering to be appropriate methods.

Interactive volume slicing offers good possibilities to identify the foci of the reconstructed image. In this way we achieve impressions of the object coded in the hologram. Our system provides three views exhibiting the intensity of the electric field on each slicing plane and one view displaying the cutting planes in three dimensions to enforce the impression of the reconstruction. The cutting planes are moved interactively through the volume data set.

Volume rendering provides the employment of translucency. Therefore, we defined a threshold operator that determines what is transparent and what is opaque.

The techniques described above are implemented in C++ on Silicon Graphics workstations. For the three-dimensional volume visualization we use the graphics libraries OpenGL [8] and VTK [11]. By using graphics hardware supporting three-dimensional textures [2] we obtain a speed-up for the rendering process.

Calculation of the volumetric data set and its visualization are separated in different modules. The calculation module runs as a server process on a single machine, the visualization modules can run as a client process on different computers (see Figure 5). Each client process sends an

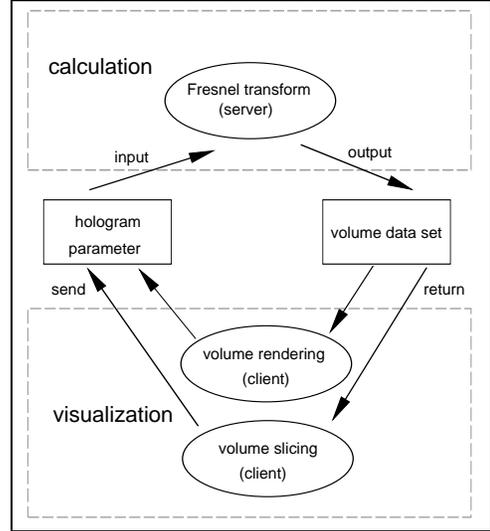


Figure 5: Architecture of the software

image depicting the hologram and a parameter set needed for computing the volumetric data set to the server. The parameter set contains hologram resolution, start and end distance and the step value for the calculation of the Fresnel transforms (see Figure 4:  $z_s$ ,  $z_e$  and  $dz$ ). The server program computes the Fresnel transforms and returns the requested volume data to the client. Now the client is able to interactively display the data set.

## 5 Results

In Figures 6–9 we show reconstruction results of two holograms, one displaying a rectangle which is parallel to the hologram plane, the other displaying a line in three-dimensional space. In both cases the hologram consisted of  $128 \times 128$  points, the calculated volumetric data sets consisted of  $128 \times 128$  pixels and 64 layers. On an SGI Onyx2 with two processors, the computation of the data sets requires ten minutes each, the volume visualization is performed in real-time.

In the first case a rectangle was placed in a far distance compared to its extensions. Figure 6 illustrates volume slicing through the intensity field which was generated as described in Section 4.

The upper left part of Figure 6 shows a cutting plane which is parallel to the hologram plane. The chosen distance equals the distance of the object during recording, so the result is a sharp reconstruction.

The upper right and the lower left parts of Figure 6 show slices which are perpendicular to the hologram plane. Here, the focus plane of the object becomes apparent through the focus of the two beams. The small white lines drawn above the cutting planes help positioning them in space.

In the lower right part of Figure 6 a three-dimensional representation of the slices is shown.

Figure 7 depicts volume rendering of the reconstruction field. Figures 7(a) – 7(c) show the same volume, while increasing the translucency threshold. By this variation the structure of the reconstructed rectangle becomes visible.

The figures demonstrate the optical effect of a wide focus area. The reconstructed object seems to have a spatial extension in the third dimension. This results from the far distance to the hologram plane during recording.

The reconstruction of a line inclined in space is demonstrated in Figure 8. The line is composed of a number of points. Here, the cutting planes are positioned in a way that the focus area of the points is perceived. The upper right part shows a slice through all points of the line.

The effect of an alteration of the transparency threshold for displaying the intensity field is shown in Figure 9. Again, the reconstruction of the points becomes visible. In Figure 9(c) the positions of the different points in space can be detected.

## 6 Conclusion and future work

In this paper, we applied volume visualization techniques like volume slicing and rendering to holographic reconstructions. The results shown in Section 5 demonstrate the usefulness of these techniques during exploration of holographic reconstructions. In contrast to the so far used two-dimensional techniques, the user is able to detect spatial patterns, like focus planes, directly.

In the future we will apply further techniques for volume visualizing to hologram reconstructions. This includes more sophisticated methods to tune the visualization like choosing the translucency threshold automatically. This is needed to remove the blurring effect. The resulting reconstruction will then be saved as a set of points in three-dimensional space. This will enable subsequent post-processing steps that help for example optimizing the holograms.

An application of our methods for the visualization of holographic recording and reconstruction is prepared for educational purposes. The interactivity of our approach should be able to help understanding the physical background of holography. Future work will investigate such possibilities.

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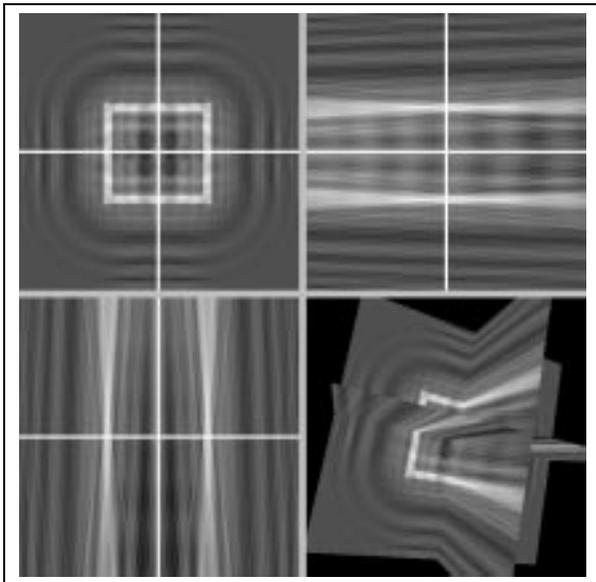


Figure 6: Three-dimensional visualization of a holographic reconstruction by three orthogonal cutting planes through the intensity field and their spatial arrangement.

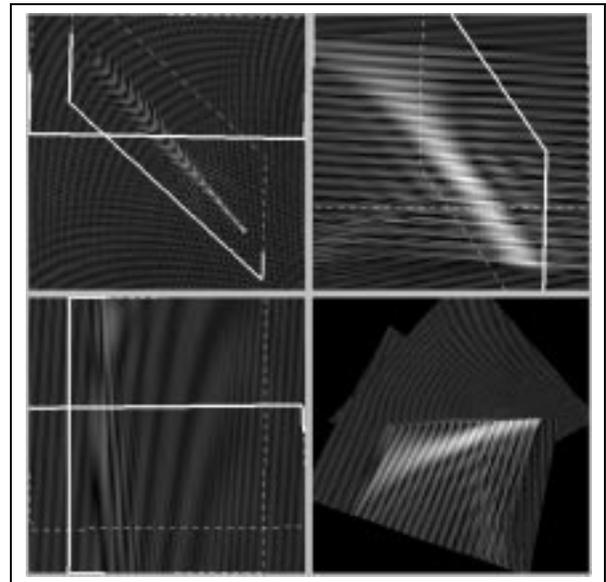


Figure 8: Non-orthogonal cutting planes through the intensity field of a reconstructed line. In this case the line was assembled out of a number of points.

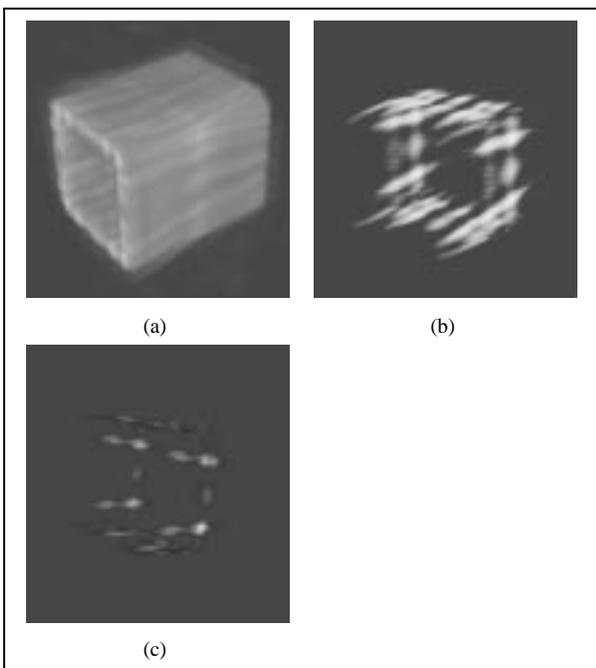


Figure 7: Volume rendering the intensity field of a hologram reconstruction with increasing translucency threshold: (a) low threshold, (b) and (c) higher thresholds.

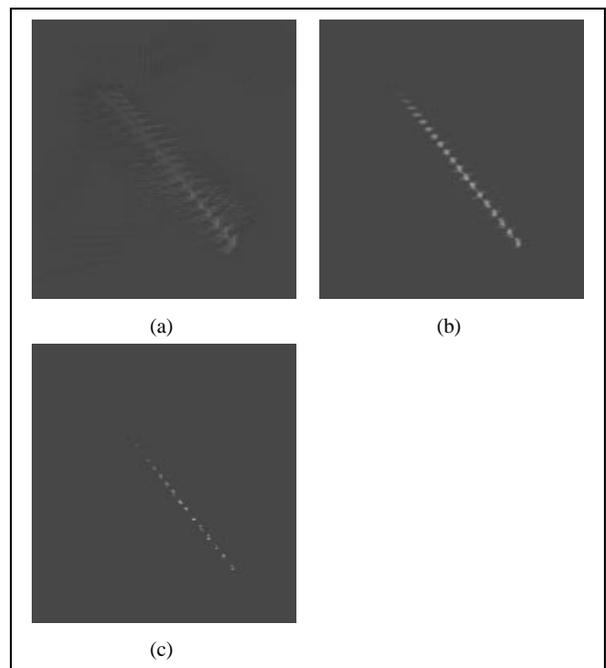


Figure 9: Increasing the transparency threshold of the intensity field enables identifying the object coded in a hologram. Using a high threshold causes only the focus points to remain.