Digital Holography

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Abstract

This paper focuses on digital holography. The techniques for producing holograms based on a computer-generated content are outlined, focusing on different approaches and technologies.
The extended capabilities of using digital holograms for a variety of applications are also outlined in a detailed way.
In addition the way of creating digital-content for a hologram is described based on the experience of generating this content by us. Difficulties and different techniques will be discussed.

Keywords: Hologram, Digital Holography, 3D Visualization, Holographic printer.

1. Introduction

Since first introduced in the early 1960s by Dr. Dennis Gabor holography became a challenging technique for the visualization of three-dimensional (3D) objects. By reproducing the light wave emerging from an object in an exact way, the observers get a realistic depth impression of the object stored within the hologram. Recently the development of higher quality holographic emulsions has enabled a wide use for holograms. Optical holograms are used as copy protections, data storage and holographic optical elements. Beside there are a lot of applications making use of the stunning graphical quality to represent real 3D objects, without being physically present in this certain place. Examples include medical visualization, showcases in museums, historical research, advertising and marketing.
At the moment a lot of research interest is put into the idea of computer-generated holograms, which can be subdivided into digital holography and electro-holography.
Electro-Holography aims at the realization of computer-generated holograms in real-time. Simulating the optical interference and calculating the interference pattern can achieve this. Due to the massive amount of data to be dealt with, today's computer-technology still sets limits to this generation of holograms in real-time, such as low color and resolution. The other case of building holograms based on computer-generated content is the digital holography: Holographic printers (like the one introduced by Zebra Imaging 1997 [Klu02]) apply small fractions of the photometric emulsion with a computer-generated image. This aims at the generation of conventional holograms with digital content rather than real scenery. Pre-Calculated data, like CAD-drawings, renderings or images can be stored into a conventional hologram making it attractive for a lot of applications like the visualization of upcoming buildings, advertisement, and design studies.
Due to the amount of data that can be stored into a digital hologram the quality being achieved can be great.
This term paper deals with the basic mathematics behind digital holograms, talks about different techniques to produce them, especially focusing on rendering methods, deals with holographic hardware and takes a look at the possibilities that could be achieved with it. In addition we also represent a typical process of building digital-generated content for a hologram we did ourselves and talk about difficulties and further challenges.

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2. Technologies

2.1 Mechanical creation of holograms

One has to differentiate in computer-aided holography between the electro-holography (like holovideo by the MIT [Luc97]) and the so-called digital holography. Electro-holography aims to be interactive or even real-time and flexible. So they use holographic displays to show the hologram, depending on a high level of computation.
Digital holography tries to display the image as realistic as possible, mainly on static holographic planes. They consist in a holographic film comparable with a photographic film. But this one is able to reproduce the light waves correctly, including the phase shifts being essential to illustrate the image three-dimensional. In the following some more aspects of digital holography are worked out in detail.
The object that should be turned into a hologram has to be processed digitally. Either the object is already a computer-generated 3D-Modell, that means it was produced using a computer-aided program like a CAD-simulation or a modelling tool, or it is, like in the case of our self-made content for the hologram, a real object that has been photographed out of all needed and wished perspectives. The photos can be digitalized to use them within a digital context. The digital model hast to be rendered to provide all different perspectives, too.
To produce a hologram out of this digital content there are different approaches, based on a different number of working-steps, miscellaneous rendering types and techniques.
Before taking a close look at the different possibilities, the technique of producing the digital hologram as a real object (that means to expose the holographic film plate) is introduced, being independent from the different rendering approaches. In the first instance holographic printer have to be named, being able to produce the digital hologram.
To transform the computer-generated image (out of an LCD) on the holographic film plate and make it 3D is carried out with the help of special printers that have a mechanical mask for punctual exposing light, being able to move the

film plate (or the mechanical mask) to every single different position and exposing the picture to it.
The printer has to be very precise in the meaning of position and the duration of the exposure of the image. The mechanical effort is high for moving the holographic printer in a precise way; so holographic printers are still quite expensive. Future approaches might be more widely affordable.
For every picture containing on the LCD, a hologram should be produced. The mechanic of the holographic printer moves the holographic film plate (or the mechanic mask) to the right position and focuses it.
Every picture on the LCD-Display contains a different perspective, so the printer has to choose the right position.
The exposure of the image has to be performed on a small-defined area, so the mechanical mask has a small slit (look at Figure 2) on one side of the printer for the object beam and another slit on the backside for the reference beam. You can easily adjust the size of the slit using micro screws on the side of the slit. In the holographic printers we found technical sheets of, the size of this slit varied between 14 and 99 mm in the vertical direction and 0-5mm in the horizontal direction. The slits are shaped in such a way that they do not cast any shadows on the photographic film plate that would of cause result in interferences on the holographic film plate.
The LCD-Image is now positioned in front of the holographic printer. The printer chooses a position and due to the interaction of the object-beam and the reference-beam the desired interference can be achieved, which is needed for the hologram and stored on the film plate.
Depending on the hologram, half parallax only (HPO) or full-parallax, pictures have to be stored in every location on the image in a vertical and horizontal way.
After describing the mechanical construction of digital holograms with holographic printers we are going to introduce several methods for creating the Holograms in the next chapters. Particularly we differentiate between the Two-Step-Method and the One-step method, dividing in the number of working processes. The different techniques will be described in detail within the following chapter.

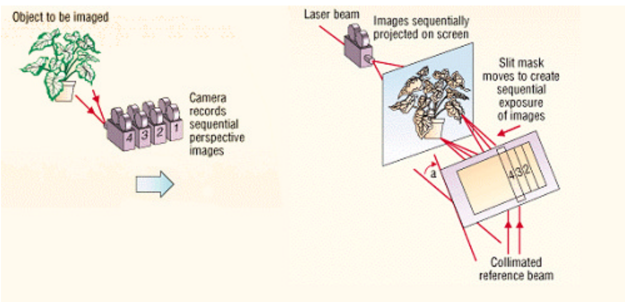

Figure 1: The principles of a holographic printer: Using an LCD to provide an image, using a mechanical mask to expose the image to certain points on the film plate

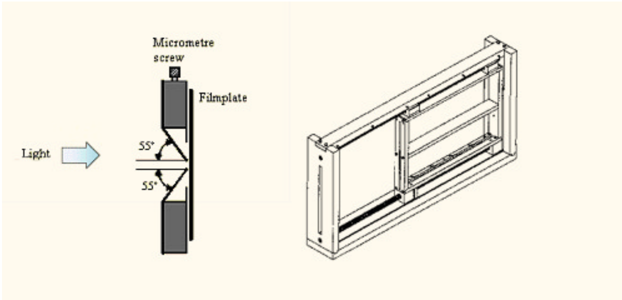

Figure 2: The slit of a holographic printer and a schematic illustration of a printer

2.2 Different approaches to produce holograms

Two-step-method

The first method described is the two-step-generation of holograms consisting of two elemental working processes. As a first step there is the creation of a Master-hologram (this is not visible under normal white-light) and on the second step the creation of additional reprinting of this holograms, which can be watched under normal lighting conditions.
All Perspectives the object can be viewed of have to be considered and produced. To do this we have to divide between computer-generated content and real objects.
Real Objects that should be turned into a hologram have to be photographed out of every desired and needed perspective, remaining the distance between the camera and the object. The simplest way to achieve this is to build a track for the camera, where the camera can be moved to simulate all possible views for the spectator. Of course there has to be a discretisation of perspectives, i.e. using every degree for one perspective. In case of a horizontal parallax the camera is moved on a half-circle-track around the object. Another possibility is moving the object while remaining a fixed camera positions (This is what we did when we created the pictures of a headlight for a digital hologram, described in a later chapter). The functionality of the two-step-method is quite easy, but the number of necessary pictures is high, making it very elaborate.
Especially in the case of full-parallax holograms, where the number of pictures to be taken is of quadratic complexity due to taking a picture of every single vertical-horizontal combination possible. You would need to move the camera on a way complying with a hemisphere. In addition, due to cases where the object is rotating there might be another rotation axis, which a single turntable can't provide.
If the object is a pure computer-generated 3D-Modell it has to be rendered out of every possible perspective, too. Due to the recent evolution in the graphics hardware this can be easily performed in real-time for a low quality object or be prerenderd to obtain higher quality.
These objects are used to generate holograms using the holographic printers described earlier in this paper. Every single possible perspective is shown on the LCD-Panel and exposed to the exact point, creating the interference pattern with the reference beam.
The real image in the resulting print with this technique is pseudoscopic, that means inverted. One could think of

valleys turning to heights and vice-versa. This first print is called Master-Hologram. To obtain a visible orthoscopic hologram the hologram must be lighted in a way that the virtual image becomes visible. An alternative is to produce a transfer hologram. You make inverted reprints of this master-hologram, by using a negative hologram-making process out of one image. It is a lot cheaper to make reprints than making the master-hologram. These reprints are visible with white-light illumination, which means there is no more laser necessary to visualize the object. It is possible to loose quality due to this technique, but it is also possible to make bigger reprints. In example the magnification2X method doubles the size of the hologram with the help of a lens, placed in the middle of the master hologram and the reprint. To get full-color holograms three different master-holograms are created one for each color and then combined in one-transfer hologram.
The Two-Step-Method has the advantage of producing a high amount of reprint-holograms out of a master hologram in a less costly and especially faster way. In addition it is possible to choose only a part of the master-hologram to produce different transfer-holograms with different viewing-zones out of the same object.

One-step-generation:

Using a master-hologram to make a lot of reprints is useful, but for an easier work with holographic printers and to save extra hardware-equipment there should be another method. Especially when thinking of a future desktop-holographic printer the one-step-method introduced by M. W. Halle [Hal97] could be a solution

To obtain a hologram without creating a master-hologram first the object has to be rendered with a combination of a pseudoscopic and an orthoscopic view out of the object to achieve an impression, being interpreted as a „correct" image by the spectator. No Master Holograms has to be produced. With analogue cameras this effect could be achieved with a big axis-symmetric imaging lens (Figure 3). The resulting image would not be consisting of the cameras view, but coud capture information about parts of the scene beig ocated behind and in front of the pin-hole-apperture. By making a reprint of this image a viewable hologram is created.

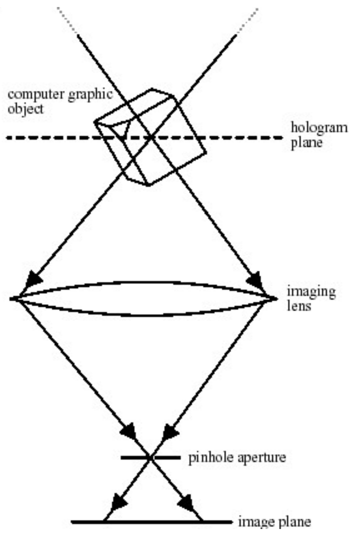

Figure 3 :
With an imaging lens, the apperture of pin-hole-cameracan be transferred into the middle of the scene to capture information about parts located behind and in front of the apperute

Such a camera-set-up is difficult to simulate with computer graphics, because computer graphic doesn't use lenses. But in advantage we could position our virtual camera on the holographic plate, which could not be achieved with a real camera colliding with objects. By setting up a camera on the holographic plate facing forward there is the disadvantage of not being aware what is between the object and the viewpoint.
According to this a camera-set-up with a double frustum was created. One frustum is facing to the viewpoint, the other one facing in the direction of the view vector. The camera is positioned on the holographic plate, rendering the images of both perspectives. The image resulted in the frustum facing against the view direction has to be rendered pseudoscopic the other image has to be rendered orthoscopic. This results from the ray directions in the pinhole model (Figure 3).
Simulating this camera-set-up is difficult, because the typical computer rendering approaches are based on a pinhole camera. A few other approaches like ray-tracing don't supply the flexibility, and the quality of ratraced images cannot be displayed by common holographic printers in an accurate way, so rendering is realised with flexible graphic-pipelines like OpenGL. To simulate the camera-set-up and to obtain a high rendering speed different techniques exist.

Rendering approaches

To realize the one-step-method and to simulate the camera-set-up introduced in the upper chapter there is a special rendering method. [Hal97].
The virtual camera has to be placed on every aperture of the holographic plate collecting the information of the view direction and of the direction to the viewpoint.
As a solution there is a double-frustum set-up. The camera-position is on the holographic plate, one frustum rear facing towards the viewpoint, called conjugate camera (rear facing) the other frustum-facing forward in the direction of the view-vector.

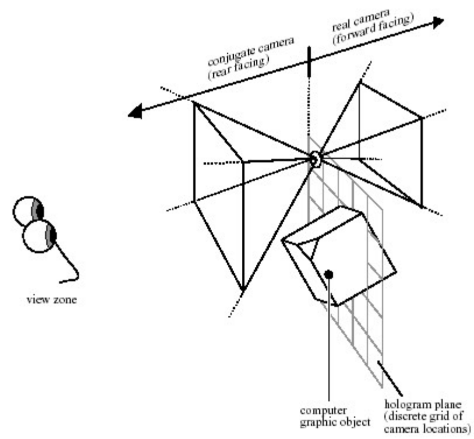

Figure 4: An illustriation of the double-frustum

The whole sequence of images is created moving the camera position to every single point on the holographic plate maintaining the view direction of the fixed viewpoint.

The frustum rear facing the object has to be rendered pseudoscopic, the other one orthoscopic.
There are problems by using the standard rendering pipelines, because of the pipeline architecture, that tries to void pseudoscopic images that might be aberrant.
To produce holograms in one step rendering a pseudoscopic view is necessary. For that reason we have to transform the orthoscopic camera in a pseudoscopic one, by using certain capabilities of the graphics APIs. OpenGL can provide all necessary transformations to render a pseudoscopic image:
The depth-buffer has to be reconfigured to prefer objects being positioned far away of the camera and occlude closer ones. This can be achieved with the Depth-Func of OpenGL. If the Depth-Test is enabled setting the Depth-Func to the parameter GL_GREATER will provide the needed effect. The Depth-Func specifies the conditions under which the pixel will be drawn. By using GL_GREATER the pixel passes if the incoming depth value is greater than the stored depth value.
The viewport has to be flipped from left to right and from up to down, depending on the orientation of the orthoscopic system. OpenGL Optimisation like backface-culling causing the removal of all unseen surfaces has to be deactivated or changed to removing the front-surface.
There is also a change in the way lighting has to be performed in a pseudoscopic context. In an orthoscopic scene we use the three typical vectors N (normal of the surface), E (vector to the eye) and L (vector to the light position). The Eye-vector is facing from the viewpoint to the object, but in a pseudoscopic system this is opposite. Using the same vectors will cause incorrect lighting, so we need to set up an inverted camera-system described by the vector C*.
We also need to transform the other vectors. OpenGL can flip all Normal vectors by simply adding two-side-lighting. New normals (= N*) exist with an orientation facing away from the camera. A pseudoscopic lighting-system can be achieved by the Vectors N*, C*, and the new vector L*.
L* is a pseudoscopic light with the same properties as an orthoscopic light, but the opposite direction. The resulting system can be described as followed: We have a new camera-system C*, being located on the holographic plate and facing toward the viewpoint and the camera system C standing on the same spot and facing away from the object in the view-direction.
To achieve a complete scene, the image of the System C has to be overlapped with the image of the system C*.

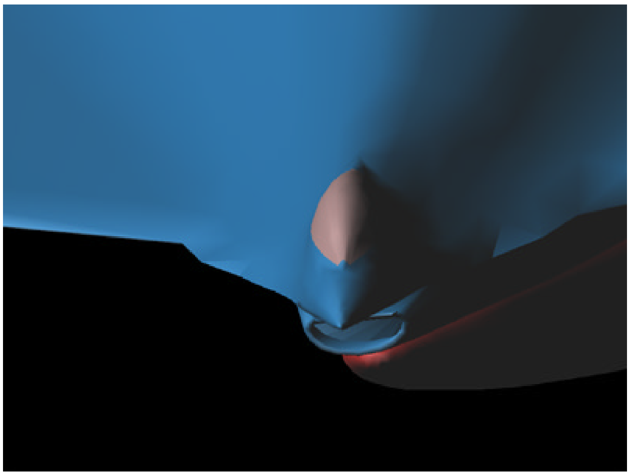

Figure 5: Renderd scene for one perspective using the double frustum

Objects that are seen by C* are in front of objects seen by C. This can be achieved in OpenGL by rendering the scene out of the perspective of C, changing to the camera perspective of C*, clearing the depth-buffer to a value close to the camera and rendering the scene with C*.
The scene must be rendered with an off-axis projection, because of the following. The focal planes of all frustums in the view direction must be parallel to the holographic plate in each projection. The direction of the frusta is orthogonal on these planes. Now the projection must be centered to the fixed position of the projection screen. The projection screen is where all the images are rendered. So the double-frustum must be sheared to recenter the projection onto the projection screen. Shearing means, that if the one side of the double-frustum is shifted in a specific direction the other frustum must be shifted contrarily, but the direction vectors stay orthogoally on the holographic plane.
We tried to implement this algorithm by ourselves and it worked quite fine. Pseudocode looks like this:

```
// The view is directed from the
// holographic plate in direction of // the
viewvector

       glClearDepth(1);

//set the depth-function to less so //we
obtain a orthoscopic image

       glDepthFunc(GL_LESS);

       projectOffAxis(front_params);

       Drawtheobject();


// Flip Light position for a pseudoscopic
// image and do two-side-lighting

       LightPosition[0]=-LightPosition[0];
       LightPosition[1]=-LightPosition[1];
       LightPosition[2]=-LightPosition[2];
       glLightModel(GL_LIGHT_MODEL_TWO_SIDE)
       ;

// Setup View position facing towards the
// viewpoint (rear facing)

       projectOffAxis(rear_params);

// Clear the depth-buffer to a value close
// to the camera.

       glClearDepth(0.01);

//set the depth-function to less so
//we obtain pseudoscopic image

       glDepthFunc(GL_GEQUAL);

       Drawtheobject();
```

Another problem is the clipping-plane used by computer graphics. The near-clipping-plane can not be set to zero.

For that reason the cameras have to be positioned as far from the holographic plate in a opposite way as the near-clipping-plane is set.

Our case:

Like mentioned in the introduction we created the content for a digital hologram. We will present the exact camera-set-up and the creation in the last chapter but we will explain the method of creating in this part.
The company Liti3D[tm] that produces our hologram uses the two-step method. They create a master hologram, which can be reprinted. This results in a higher price for the first hologram and cheaper prices for additional reprints.

Data

In this section an example is calculated which shows the amount of data that is stored in digital holograms. Imagine a full-parallax, full color hologram 30 x 22 cm large with a hogel size of 1 millimeter on the fringe pattern. The outcome of this are 66.000 hologram points each with the data of an image e.g. with a resolution of 1024x768 pixels and a color depth of 24 bit. That results to a complete data of about 145 Gigabyte.
In comparison an analog hologram of 10 x 10 x 10 cubic cm with a viewing degree of just 30° already has a data volume of about 25 Gigabyte. The German company Bayer predicts of holograms as data storages with a capability of one terabyte. It bases on the amount of memory of photo refractive medias that are about 200 Terabytes per cubic cm.
In electro-holography the hogel size must be much smaller because otherwise the modulated light would not diffract properly. If it is assumed that the hogels have a size of 0.5 microns the whole data expands to the 2000 times magnified in comparison to digital holograms. That is why the holovideo system still is not able to handle larger than palm-sized holograms interactively. The algorithms for fringe computation are that slow so that only 6 Mbytes of data is manageable in real-time.
Sure there exist methods of compressing this data like the above mentioned difference specific approach, but they are still not good enough to reduce the data to make it manageable in interactive rates.

2.3 Fringe computation

This section is to describe the methods the electro-holography uses to display holograms. Electro-holography is based on fringe computation, that means the hologram is not rendered, but the interference pattern, which is divided in fringes, is simulated and calculated. The fringe computation is the most intensive part for computation power, because every object point affects every point on the hologram. Mark Lucente, developer of holovideo, mentions two different methods for fringe computation [Luc97]. The Interference-based approach, which simulates the light waves and computes the interference out of this, and the diffraction-specific approach, which computes the pattern backwards with the help of basic fringes.
Interference-based is the more conventional approach with a high demand of computations. According to basic optic laws a light wave front is represented by a complex expression. For the computation of the interference pattern the calculation of every wave field from every object point is required. The interference between all these fields must be estimated. Therefore a high number of complex arithmetic operations, roots and trigonometric functions, which lead without fail to the use of very extensive floating-point operations, are necessary.
If the object is three-dimensional, the complexity of the interference is increasing. In order to manage this, the object is cut in several planes, which can be computed separately. This method is only practicable for interactive applications, if the number of sampled object points is quite low, resulting in a non-realistic image

The difference-specific approach presumes that the fringe pattern is sub sampled regionally and spectrally in hogels. For each hogel the scene is rendered with an orthographic projection allowing for a discrete sampling of space and spectrum. Out of this hogel vectors can be created in a simple way [Luc96]. Then an array of these hogel vectors is multiplied (inner product) with an array of basic fringes. The basic fringes are precomputed. For every possible object point the appropriate wave field is calculated. The data is combined with the actual object. This can be performed very fast by a standard computer graphics subsystem with the use of the accumulation buffer. Compression is possible at the sub sampling of the fringe pattern. The compression ratio (CR) is the ratio between the size of the fringes and the hogel-vector array. Till 8:1 it is still invisible for the human eye. 16:1 and 32:1 still reach for good images. This method is predestinated for interactive or real-time applications.

There is another approach from Christoph Petz and Marcus Magnor [PeM03]. They developed a very fast method rendering full-parallax holograms also on standard PCs with advanced graphic cards. They use the OpenGL rendering pipeline to accelerate the calculations. There are fewer commands but there are enough for the superposing of the wave fields. They reached rendering times that are under one second at a resolution of 512x512 with 1024 primitives on a GeForce4 card.
The main advantages of digital holography over computer graphics are described in the following. Digital holograms are auto stereoscopic, so no glasses or comparable devices are needed. This and the wide viewing angle of about 110 degrees make digital holography usable in the public. Scalability originates in tiling methods, so that large-scale holograms can be composed by multiple smaller ones, so called tiles [Klu01]. They are attached with a gap of just 0.5 millimeters. Additionally there is a small angle between each tile so that the hologram is merging together. A tile-to-tile color consistency supports the not-recognizing of the gaps, too.
Digital holograms can be full-parallax or horizontal-parallax only (HPO). This depends on the application, because if the hologram is placed like a picture on a wall, or like a monitor, HPO would be preferred because the viewer's vertical angle stays nearly constantly. But if the hologram is placed on a table for displaying a special terrain like in Figure 5, full parallax is necessary.
Full color holograms become realized in the same way colors are displayed on computer screens by super composing the three basic colors red, green and blue. In holography three different kind of lasers have to be used

respectively three calculations have to be made because the different wavelength of the colors have an impact on the whole calculation.

3. Digital Holography: Applications and Use-Cases

By using digital holography it is possible to rebuild images in a stunning quality with accurate experience of depth within the picture. This makes multi-scale, full-parallax, digital holograms greatly useful for a lot of applications depending on the impression of depth and a high quality mapping of a 3D-Object. Still holography isn't interactive yet, but i.e. interactivity can be added by combining the hologram with digital rendered elements represented by a light beam. [Bim03]. Future Holograms, based on the electric holography, might be able to provide the real-time generation of high quality to provide a high degree of interaction.
But still at the moment holograms are useful for applications requiring the input of a very complex data.
Holograms can be viewed by more than one person from different angles and even contain different perspectives of the same object. This makes digital holograms a great tool for Consensus Building. Representing complex data in an accurate way might be helpful for discussing about the object.

Consensus Building.

No additional technical equipment like used in the virtually-reality science, or the augmented reality-science, for example head-mounted Displays or stereoscopic walls have to be provided. This might simplify the level of discussing as well as limiting the cost of equipment. Still, in comparison to Virtual Reality or Augmented Reality the holograms unfortunately remain non-interactive.

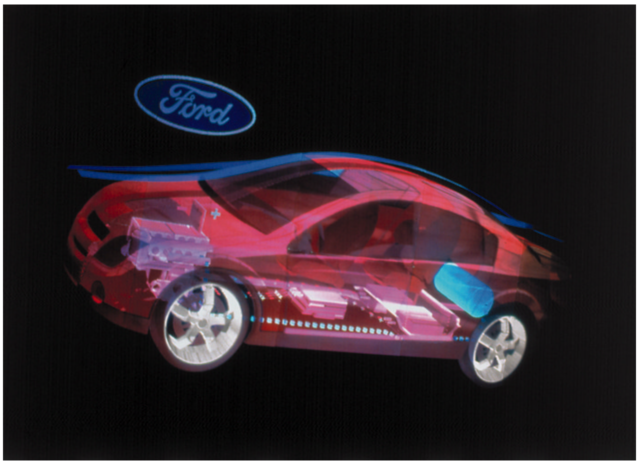

Figure 6: Using digital holography of a Ford-automobile for **Consensus Building** and advertisement purposes. This model may i.e. allow designers to discuss different shapes or models. **Consensus Building can be easier achieved by using a 3-D-impression of depth.**

An example for the use of a digital hologram for Consensus Building is the automobile industry. [Figure 4] Multiple Designers could use a large-scale hologram to discuss different approaches for a new car-design. This hologram can be created right out of the production software (i.e. some 3D-Modelling-program) by the use of holographic printers. By remaining the real impression of depth within the hologram, the designing process might be far more effective by providing a "real" impression of the future-car model.

Another example is the representation of cartography. [Klu02] A great amount of the earth surface has been digitally recorded, but to get a real impression of depth out of the 2D-Coordinates is very difficult. Animated computer-generated costly real-time rendered flythrough are a possibility to get the impression of depth for a particular surface. This technique has disadvantages due to the high sophisticated hardware, the difficulty of interaction between multiple users and to the required motion, which is necessary to achieve a depth impression.

Digital holograms can create a volumetric image of the surface, which can be easily viewed without additional glasses/hardware and from multiple persons at once. It is possible to discuss the imaged scene like watching the real one out of a helicopter. Due to the high-quality graphical representation possible in digital holograms and the new technologies of building true-color holograms, the surface can be highly detailed.

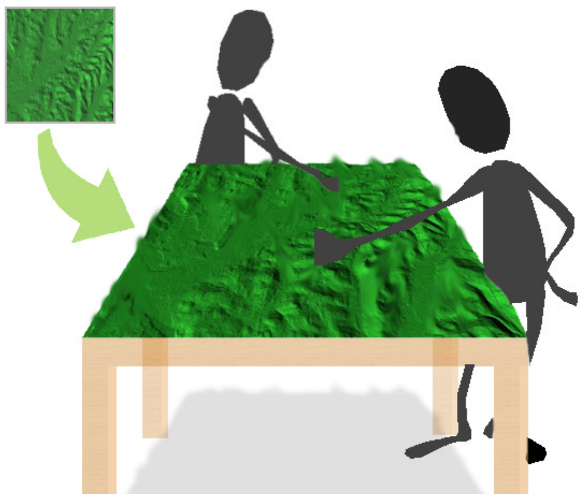

Figure 7: Using digital holography for visualizing geometric data, i.e. for scientific or military purpose

By using a full-parallax hologram users can watch the landscape from a great variety of angles.
Using a digital hologram could enhance the work of geologist. Another possible use of terrain-visualization would be in a military purpose.
The digital hologram could represent strategic information about a certain terrain like the exact locations of target or

could be used to find a safe corridor for airplanes by considering defensive information like radar lobes.
In addition transparent holographic layers can be added to change information on the same surface, so that strategic changes can be visualized onto the same holographic landscape.

Decision-making

In a lot of cases decisions have to be made out of a special level of information. This information depends on a wide area of research activities, different levels of knowledge and lots of people that took part in gathering this information. For example a lot of times engineers may have a complete understanding due to their technical background, but decision-maker may not.
A hologram is helpful in presenting complex data disburden the challenge of decision-making.
This will work especially in those cases where a single 2-D presentation or a simplified 3D rendering doesn't cover the amount of information and it is useful to obtain mobility for presenting the information on different locations.
The autosterescopic capability doesn't need additional hardware. In addition inexperienced users might prefer the hologram as an autosterescopic view, rather than using stereo-glasses that might be unknown.

Presentation

Due to the high-quality representation of a 3D-object that isn't in the same space holograms are great mediums to present object. Especially when rebuilding the object, as a physical matter is obviously expensive, holograms might be an alternative. Digital holography, in comparison to "classic" holography (which produces higher-quality-images) can produce more enhanced objects with additional information build with a computer-system. Showcases in museums and other educational facilities are a typical example for this use of holograms. A lot of research fields like archaeology or paleontology, that need high image-quality, too, could profit from Holograms, and in special cases, like enhanced information, particularly from digital holography.
Digital information may contain additional explanation, colors, structures and so on.

Advertisement:

More like a subpart of presentation, digital holograms could be used for advertising. Especially the construction of large-scale digital holograms (build up of different tiles) is an "eye catcher". By using computer-enhanced graphical content different effects regarding to the desired effects can be achieved. And it is less costly to represent 3-D Objects on a small spatial area rather than presenting the model itself.
A good example for this is the presentation of an automobile in a small place with a high level of attraction. [Figure 4]

Art:

New kind of imaging-possibility means a new kind of art. The possibilities of the holography technique are interesting for a lot of artist, too, who can use the enhanced effects for creating new kinds of images [Figure 6].
Example includes the work of Casdin-Silver/Kevin Brown [CS98]

Figure 6: Using digital holography the creation of Art
Artist: Philippe Boissonnet, Canada

Conclusion for Applications:

As holographic-printing technology will become cheaper and a lot faster more applications will use digital holograms. Before real-time high-quality holograms will be affordable and realized, non-real-time holograms will play an important role in a lot of different fields varying from medicine to informatics. Recent advances in building full-parallax digital holograms have made them more widely useful; they are more easily available and even more accurate. Due to the need of very precise and accurate images with a real impression of depth the market will increase.
Combining digital holograms with other "conventional" methods out of the Virtual reality or the Augmented Reality research, could be a solution to the remaining big problem of non-interactivity

4. Digital Holography: Creating the content for a digital hologram

Part of our research was the creating of digital content to produce a digital hologram. We have chosen Liti3D, a company located in Virginia to produce the hologram.

Our goal was to produce a hologram from a single headlight of a car. We wanted to build a hologram with horizontal parallax only and three different viewing zones. The viewing-zones are included in the possible 110° of viewing space that means we assigned the three different viewing-zones to the appropriate angles. There should be a view from the side in the left 35°, a front-view of the headlight in the middle 40° and the back-view in the remaining 35° on the right side. On each side we added an additional area of 12.5° just to fulfill the viewing zone, so that there is no clipping of the object in these zones.

We decided to take pictures from all possible angles rather than filming the object because of the higher resolution provided by digital-cameras than the resolution of digital camcorders (which would only support PAL-Resolution). We shoot a picture at every half-angle of the object and wanted to achieve more than 110° visible in the hologram to allow easier and smoother computing of the viewing-zones.
The Company asked us to send a full 180°-scene. This resulted in taking 95 pictures on the left side of the object (35° of viewing-zone plus 12.5° added), 80 Pictures on the front-side (40°) and 95 pictures from the backside of the object (35° plus 12.5° added).

Because even small changes of lighting positions are seen in the hologram, we had to build up a consistent illumination of the scene. To achieve nice reflection-maps, we put on light a little bit above our camera facing the object to gain the stunning reflections in the headlights glass. To avoid reflecting our self, we used a time-trigger to shoot the photos. To get an idea of the setup please refer to Figure 9.
Additional any movement of the camera had to be avoids due to “swimming” effects in the hologram.

The first photo shooting failed, due to the reason of movement within the image and different lighting-conditions.
The small movement of the camera was due to the changing of the batteries and the connection to the computer to download the pictures out of the camera (lack of memory space for all pictures).

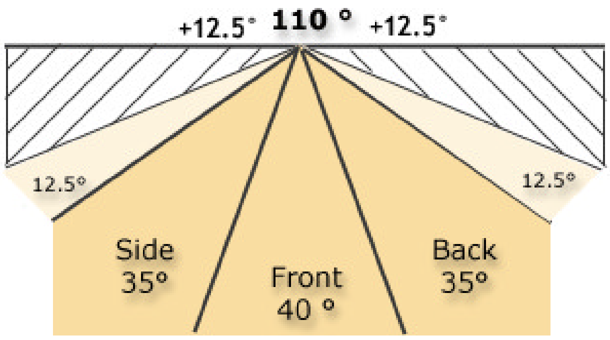

Figure 8: The viewing angles used in our generation of content for a digital hologram

Improper disabling of the white-balancing capabilities of the camera lead to different lighting conditions, resulting in a “flickering” effect within the movie, generated out of the single pictures for testing purpose.

We tried to use image-correcting software to get rid of this effect but the needed time would be far too much to correct every picture in an adequate way.
Therefore we decided at the second attempt to use another camera and to work in a photo studio. We took a 5-Megapixel digital camera Olympus E20 to take the pictures with a memory capability of 64 MB. The images size was 1024x768 with a color-depth of 24 bits. The compression was set to 1:2,7 to get all pictures on the memory card. So we needn’t change it, preventing jiggling. We used a large paper roll as a monochrome background.

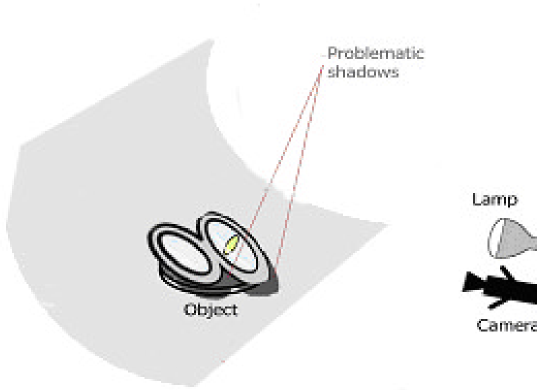

Figure 9: Our camera-setup

Conclusion

It is no question that a three-dimensional image of a real scene is more realistic than an ordinary two-dimensional image. Two-dimensional images are non-natural. The methods the human visual system uses to recognize depth in a two-dimensional image are ambiguous. Optical illusions are not rare. Therefore it would be great if it would be possible to illustrate the world in all three dimensions. Holography is one method to do this; so digital holography is in the course of digitalization a good approach to make this technology available.
The technologies we introduced in this paper show how digital holography works and how it might be in the future. Hologram printers are gaining speed and resolution making this technique more widely available. By using fast rendering approaches to get a one-step solution it might even be possible to build holographic desktop printers in the future. Especially the possibility to use pure computer-generated 3D-Objects to produce holograms might be a great way to speed up working processes.
Towards real-time holography there is still a far way ahead.
The compression of the huge amount of data a hologram contains and developing algorithms to render digital holograms in real time are doubtlessly a great aim to reach in future. Another intention could be developing computer chips that are designed especially for calculation the interference patterns very fast, like it is done for computer graphics with pixel and vertex shaders. The work of Petz [PeM03] has already described that using new graphic hardware possibilities can be suggestive, so future work could focus on evolving graphic cards especially for digital holography.

Both applications and producing technologies for holograms are important topics for the future digital holography research.

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