OPTICAL TRANSFER OF MASTER HOLOGRAM WITH 20 METER DEPTH

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Abstract

The optical transfer of a large-scale synthetic holographic master stereogram via Benton rainbow technique is discussed. The limits of this technique when the volume the rainbow hologram fills is increased to 8000 cubic meters are evaluated. Blur and accommodation present the primary difficulties. The choice of imagery plays a crucial role in minimizing these effects.

Fig 1: **'You Are Here' Logo** (depicting hologram installed on beach with lunar illumination.)

0-8194-0905-7/93/$4.00

Motivation

We are attempting to produce a large scale, large volume, display hologram which is white light viewable. The motivation for this research came from one of the authors (Paula Dawson). In her proposed piece "You Are Here" a large scale synthetic hologram, depicting sea-level changes over the past 2.5 million years, will be re-illuminated by the light of the full moon on a beach in Northern Queensland, Australia. The volume of the image, which will appear behind the plane of the plate, is targeted for 8000 cubic meters in order to match the scale and contours of the existing landscape. The synthetic hologram will act as an optical element and gather the focus of the light of the full moon at the position of the viewers eyes so that the image can appear in full color. When the moonlight strikes the holographic plate at a 45 degree angle, and the viewer is facing due North, a series of veils of color describing the negative volume of the seashore will be seen superimposed onto it. The vision of the ancient sea levels will only last for 8 minutes on any one viewing as the moon is constantly moving through the critical angle which will reilluminate the hologram. The image representing the fluctuation of sea-levels will be derived from studies made of coral growth on the Great Barrier Reef. (See Fig. 1)

Because of the huge difference in geographical locations of the two authors, one of the authors (Mary Lou Jepsen) has chosen a site in Cologne Germany to be used as a testbed in the development of this technique. The Cologne site is a ruins containing the remains of buildings that were constructed between the 10th and 15th centuries. Only jagged edge basement walls of these structures still remain. The city archeology department (Amt für Archäologische Köln) has supplied detailed plans of this site in both its present condition and in the various forms it has taken over the centuries (see Fig. 2, 3). The holographic image will abut to these jagged edge basement walls and extend them in a ghost-like way filling the volume of this smallish city block. The illumination will be with a collimated beam of white light which will illuminate the hologram from below. During the production of this hologram we will explore the limits of the synthetic holographic stereogram technique in respect to filling large volumes. The Cologne piece is scheduled to be completed by November, 1992.

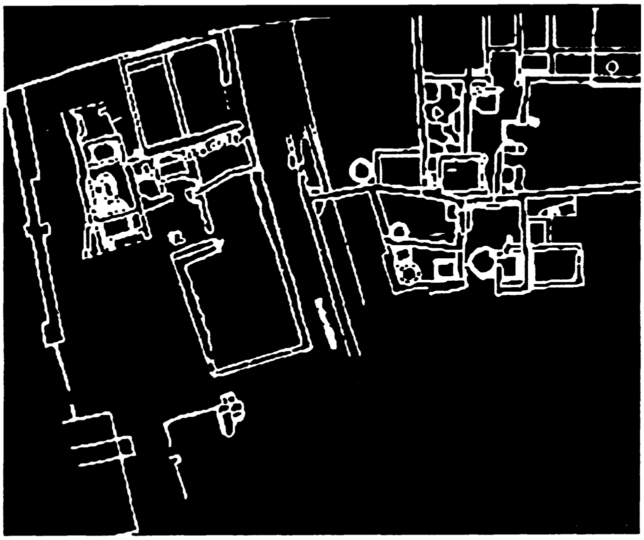

Fig 2: **Cologne Site** (Bird's eye view)

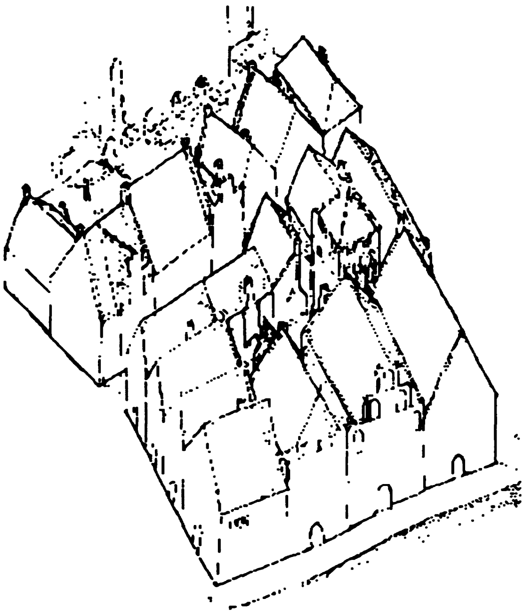

Fig 3: **Site** (15th century depiction)

Printing Technique for the Master Hologram

Originally we planned to fill these huge volumes by utilizing a computer generated hologram (CGH) master where we computer the actual fringe structure of the interference pattern. We planned to then transfer its predistorted image via optical means to create a final white light viewable hologram. Figure 4 shows an example of a portion of a CGH we computed of a spatial test pattern of 8000 cubic meter extent. This technique optimizes the complementary advantages of CGH and optical rainbow holograms. Only a narrow computer slit, with precision distortion correction incorporated, need be printed with the expensive electron beam lithography technique.

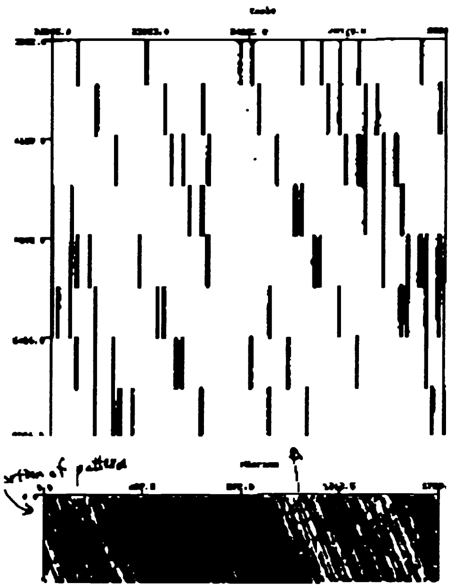

Fig 4: CGH trial (Portion of computed master CGH slit)

However, primarily due to facility availability, we have found it necessary to first explore the spatial imaging limits of the well established method used to create synthetic holographic stereograms.[1] The holographic installation for the Cologne ruins will be made with this technique. The exact volume that this hologram will fill will be determined over the course of our investigation. From these results we will then determine how to produce the "You Are Here" hologram: via the CGH technique with optical transfer, the synthetic holographic stereogram approach, or some as yet undetermined technique.

The conventional synthetic holographic stereogram technique does not allow smooth and continuous abutment of the slits, each of which encodes a 2D perspective view of a scene holographically. This non-continuous abutment leads to a viewing artifact often referred to a fence-posting which may present perceptual difficulties in imaging our desired volume. In the electron beam printing technique of CGH continuous abuttment is possible, thus the slit size can be made arbitrarily small which may lead to the perception of deeper volumes.[2] Additionally the optics used in the computation of a CGH can be made mathematically perfect in order to exactly achieve the desired fringe structure of the CGH. In the optical recording of the conventional holographic stereogram aberrations in the optical system and noise can degrade the quality of this 'analog' holographic recording. Although this degradation is often imperceptible to the human visual system, the introduction of such aberrations and noise in the fabrication process of a large size, large volume white light hologram may be intolerable. Through our study we hope to ascertain the necessity of employing the E-beam lithography technique to realize the "You Are Here" hologram.

Initial Tests

Initial tests of our new holographic stereogram printer[3] included some depth tests. The early tests were various depictions of a computer model of a building of 8000 cubic meter volume (see Fig 5,6), the camera was usually placed looking down a hallway which had non-parallel walls and thus a heightened perspective depth cue, as perspective has been shown to be strongly link to true 3D viewing comprehension. In the visual analysis of these master holograms it was difficult to estimate the perceived depth. It was thought that the space in which the master holograms were viewed was too small to allow the viewer to truly believe the depth in the holographic stereogram. The image was far larger than the room which houses either of our lasers. It was hoped that the projection of the holographic image down a true corridor of 20 meter depth, a sort of gloving if you will, would lead to better depth comprehension of the the holographic image.

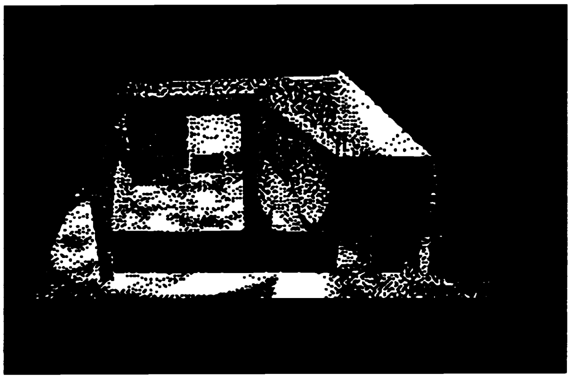

Fig 5: **Museum of El Eco** (Overview of entire building)

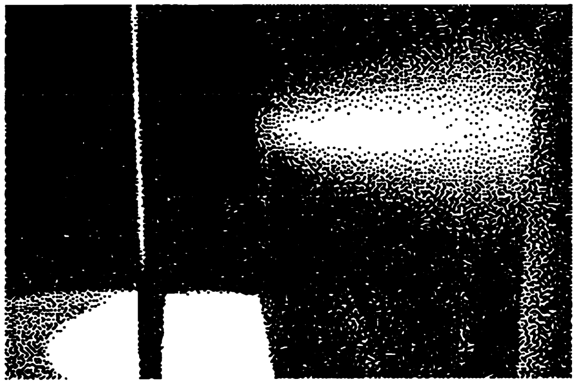

Fig 6: **Museum of El Eco** (a corridor of 20 meter depth)

However, upon white light transfer and re-illumination of these holograms the perception of the holographic image as a long narrow corridor was not obvious. When the white light transfers were illuminated so that the holographic image would superimpose on top of a true corridor some perception of depth could be momentarily perceived especially thought the use of motion parallax (e.g. moving one's head side to side). However this effect would switch back to a noisy blurry image which would appear 'stuck' at or near the holographic plate. Some of this effect has been attributed to noise which causes the viewer to see the texture of objects in the holographic image as resting on the holographic plate. Some of this noise has already been eliminated in our transfer process. Even still the very deep part of the holographic image appears to follow one as their eyes move back and forth across the holographic viewing zone. The human visual system seems to have difficulty in perceiving depth of this scale in a hologram. The effect can be likened to the moon illusion in which:

> We can't really comprehend the large size and distance of the moon so we just imagine it to be like a much smaller object only a few kilometers away, somewhere near the distance to the horizon. But, if the moon was really like this we would see its position change relative to ours when we moved. So when its direction doesn't change, we think that it is following us.[4]

Although the scale is smaller in our hologram, the effect is analogous; the content of the deep part of the image seems to follow our head as it scans the hologram back and forth. When the moon is near the horizon, it looks bigger than when it is at zenith. The perceived size and distance of the moon depend upon the distance effect of the 'terrain' or landscape in front of it.[5] It follows that the perception of size and depth in a hologram depend the composition of the holographic image in an analogous way. To that end, we will review the factors known to be involved in depth perception in order to create a new model: one which will hopefully allow us to fill a huge volume with a white-light viewable holographic image. However, we first must discuss the geometry of our setup as that must be considered in the creation of a new model as well.

Recording Geometry

We plan to re-illuminate the hologram in collimated light with a large source size, the moon. The moon doesn't reflect much light and so eventually the hologram will have to be made very efficient, for now we are concentrating on other problems, and thus plan to increase the efficiency later. However the moon does subtend a half of a degree on the holographic plate; the ramifications of this subtense with respect to our holograms are presented below.

Bandlimiting and Blur

It has been previously shown that in the white light transfer hologram of a large volume master holographic stereogram, the very deep part of the image appears vertically striped, with its horizontal detail appearing at or near the plane of the hologram. This effect has been likened to "watching a person walk behind a picket fence where the gaps between the images of the object move as if fixed to the projection screen and seem to occlude the object behind."[1] Through bandlimiting the vertical spatial detail in the distant parts of the model, and eliminating much of the model's horizontal detail, we have attempted to reduce the perceptual difficulties in the comprehension of very deep holographic stereograms. (see Fig 6) Sparsely placed edges were left in the model, but it was seen that the light source size effectively blurs these edges anyway.

$$b = W * Z \tag{1}$$

Where b is the amount of blur, W is the angle subtended by the light source and Z is the H1-H2 distance.[6] With lunar illumination and an H1-H2 distance of 1 meter, a point is blurred to 8.7 mm. We compare this figure to the bandlimit necessary to eliminate the 'double image' phenomenon between perspective views:

$$b = ((D-Z)/Z)\, w \tag{2}$$

where b is again the amount of blur, Z the H1-H2 distance, w the slit width (1 mm) and D is the 20 meters to which we aspire.[1] A point thus needs to be blurred to 19mm; the 8.7 mm blur achieved with lunar illumination could easily be increased by increasing the H1-H2 distance, but a compromise was sought between fulfilling the above criteria and blurring the input model beyond recognition. We planned to increase the H1-H2 distance if 'double-imaging' still presented a problem to us. Thus we allow the large source size of our re-illumination source to do the bandlimiting in the holographic image for us, rather than a computational algorithm.

Maximum depth resolution in holographic stereograms

We adopt an established analysis for maximum lateral resolution for holographic stereograms[7] to include blur induced by large source size.

$$r = 1.22\, \lambda\, L^2 / 0.5\, d\, D \tag{3}$$

Where r is the resolvable depth of a point, λ is the wavelength of light, d is the spacing between the eyes (0.063m), L is the depth at which the point is intended to be perceived in the holographic stereogram and D is the diameter of the lens used to image the 2-D perspective view during the stereographic recording process. (see Fig 7) To find D we use the angular subtense of the moon and get:

$$\tan \theta = D/H \tag{4}$$

where H is the H1-H2 distance and θ is the 0.5 degrees subtended by the moon. With an H1-H2 distance of 1 meter D is 0.0087 m and when H is increased to 2 meters D also doubles to 0.0175 m. These figures imply the spread of a point in depth at 20 meters to be 0.897 m and 0.447 m respectively. The closer to the plate the better the depth resolution. This analysis has shown us that while a point blurs transversely to the size of a centimeter of so, the induced lateral blur in the holographic stereogram can easily cause a point to smear to a half a meter in extent.

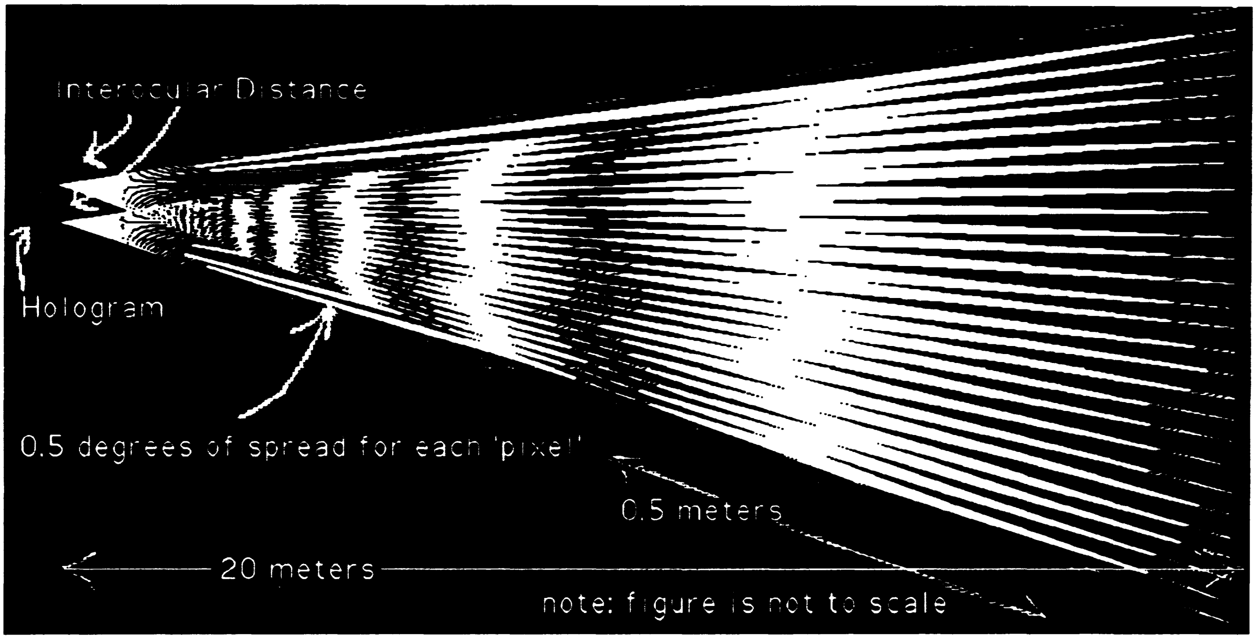

Fig. 7 **Depth Resolution** (The diamond shapes denote the smallest size pixels one can theoretically achieve in a holographic stereogram, the minimum resolvable depth at 20 meters is a half a meter).

Color Control

Synthetic predistortions which allow for color control in a parallel plate transfer, thus eliminating keystone distortion, have not been done by us as of yet. Our work thus far has concentrated on the problems associated with the transfer of just one master holographic stereogram slit, rather than three slits. The viewing zone is constrained so the image is perceived in only one color by the viewer. In the future, we plan to adopt a technique similar to that used in the Ultragram for achieving a full-color parallel plate transfer.[8]

Depth Perception

We now can discuss depth perception as it applies to the viewing geometry rainbow holographic stereograms illuminated with large source size. If we divide depth cues into 2 categories: physiological and psychological; the former are thought to be more important than the latter.[2] The major physiological depth cues are: accommodation, convergence, binocular disparity and motion parallax. Of these cues, a holographic stereogram lacks only accommodation: the eye's lens focuses at the distance of holographic sheet rather than the intended projection distance of the 3D image encoded into the holographic stereogram. The other psysiological depth cues support the desired depth perception of the latter distance. It is important to note that accommodation has the strongest effect when the viewing distance is less than 2 meters.[2] If the viewer is more than 2 meters from the holographic plate, the role of accommodation in the perception of the volume is not so significant, even a 1 meter distance reduces the problems significantly. Additionally, the model used to create the holographic image should employ *strong* cues supporting the psychological perception of depth. Some of these cues are retinal image size, perspective, texture gradient, occlusion, shades, and shadows.

The authors are unaware of any perceptual depth studies done to date using holograms; although we are performing some of our own studies. However, we draw upon the numerous 3D perceptual studies done using stereo-pairs, as this form of 3D display can properly employ the physiological depth cues of convergence and binocular disparity, unlike the studies done with physically flat image representations. In addition, both the stereopair and the holographic stereogram are similar in that they lack the accommodation depth cue. However, a holographic stereogram has motion parallax: a 3D physiological depth cue that a stereopair lacks.

Random Dot Stereopairs

Some of the most interesting depth studies are those of Bela Julesz with his random dot stereopairs. Julesz's stereopairs proved disparity alone can cause the sensation of depth.[9] We now note the implications these studies have on the realization of very deep white light viewable holographic stereograms.

Defocusing (e.g. blurring the images) does not present a problem for the stereopsis process. Thus our bandlimited/blurred images, necessary to avoid the 'double image' effect, do not present a fundamental problem to depth perception. (see Fig 8)

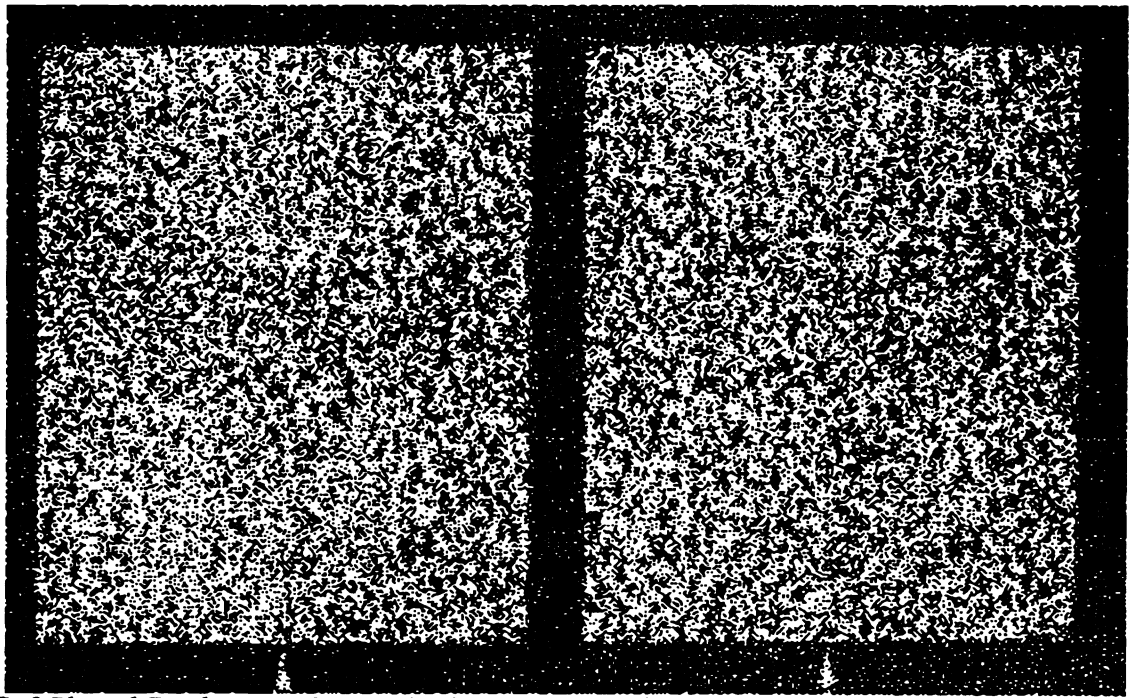

Fig 8 **Blurred Random Dot Stereopair** (demonstrates no fundamental problem to depth perception)

Additionally, one can simultaneously experience both binocular rivalry and fusion of different spectral components in a random dot stereopair. The disparity information is conveyed at some stage in the vision process by independent stereopsis channels that are tuned to different frequencies: each band is approximately 1.5 octaves wide. Each image is analyzed through channels of varying courseness and matching takes place between corresponding channels from the 2 eyes. Therefore some of the imagery in the environment into which the hologram is being projected should be of the same spatial frequency range as that of the holographic image. If there was only high spatial frequency detail in the environment than this rivalry between different channels might occur, meaning the installation site is perceived as deep and having large volume but the holographic image flat and stuck at or near the plate.

Of particular note is that perception time for a stereopair depends on the distribution of disparities in a scene. A stereopair of a spiral staircase ascending toward the viewer does not produce the long perception times associated with two planar stereopairs of similar disparity range. Scenes like a spiral staircase in which disparity changes smoothly force vergeance movements to scan a large disparity range. The search time becomes long and perception time short. It is therefore advisable that we make our hologram up of a series of planes which are oriented parallel to the hologram, and thus increase perception time while decreasing search time.

Other Perceptual Issues

The boundaries of shadows are rarely sharp but instead 'blurry', unlike surface or reflectance boundaries. Shadows nonetheless provide a good 3-D psychological depth cue.[10] An image composed of many different shadows should both give strong 3D depth cues and translate well into a large volume filling hologram even when illuminated with a non-point light source like the Moon, as is necessary for the "You Are Here" hologram. Also, the most unambiguous depth cue is occlusion and should be invoked. Thus the model shouldn't be composed entirely of shadows as true shadows do not occlude one another.

Textures are of extreme importance in the depth perception , especially those textures which give strong impressions of linear perspective. One reason nearly all of the early simple computer rendering models use checkerboards for surface is that, while being easy to compute, these textures give extreme impressions of perspective. The perspective cue has been been determined by some to be the most important for depth perception in stereopairs.

We also note here, that the human visual system will accept much bigger disparities than occur in reality and thus the 3D effect can be made more striking. Doubling the distances is generally done in 3D movies and Viewmaster (TM) Viewers. This doubling increases the difference between the perceptual cues of accommodation and convergence. Others suggest weighting the psychological perceptual cues more strongly than the physiological ones to achieve the desired depth thus allowing for a decrease in the differences between accommodation and convergence and therefore reducing eye strain.[11] This study is the subject for future work.

Currently we are not exaggerating either parallax , linear perspective or any other depth cue, instead we invoke the exact impression that a texture receding back 20 meters in depth would yield, with a camera snapping pictures of a scene every 2 mm: as the width of the slits that we are using in the holographic stereogram mastering setup are 2mm in extent.

New Model

A new spatial test pattern was recently rendered, mastered, and transferred; the image was composed of elongated parallelpipeds with checkerboard patterns on them. These structures were 1 meter wide and 10 meters high and were placed in strategic places over the true scale computer model of the site in Cologne. Some of parallelpipeds were placed as far as 35 meters away from the camera. Very high contrast was used as our process of mastering, transferring and reillumination currently reduces the contrast we can achieve significantly. The planes of the rectangular parallelpipeds were oriented parallel to the plane of the hologram, as the perception of such surfaces is known to be easier in stereopairs; also lateral detail of finer than a half a meter was not invoked, as our analysis has shown that higher resolution at 20 meter depth in a holographic stereogram may not be realizable with solar or lunar illumination. (see Fig 9)

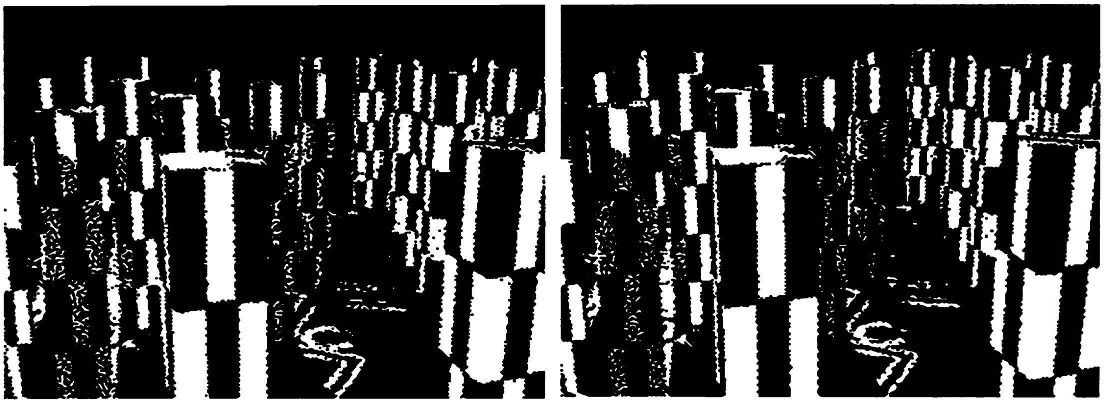

Fig 9 **Stereopair of Model** (A spatial test pattern of 35 meter depth: superimposes over detail in the Cologne Site)

The only transfer of this master thus produced is extremely noisy, and this noise clearly limits the perceptual depth. However, when looking at even this noisy, first-off transfer with solar illumination, one can see the holographic parallelpipeds superimpose on structures in the environment. As we reduce our noise problems and create better models that will glove into a site we expect marked improvements.

We are currently photographing rendered frames off a curved computer screen as well as transferring in 514nm Argon laser light despite the fact that we master in 633nm HeNe light. We are in the process of addressing these issues and also acquiring a better diffusion screen. Progress goes well and the piece for the Cologne cite is schedules to be completed in early October 1992.

Conclusion

Several white light holographic stereograms of at least 20 meter depth were made. Perceptual difficulties interfered with viewing comprehension in all but the most recent hologram. The model for this hologram was constructed after a careful examination of recording and reillumination geometrical constraints and perceptual issues regarding depth. Noise is still a minor problem affecting depth perception, but techniques for making 'cleaner' holograms are well established and are currently being applied. The first art piece using this technique is an outdoor hologram that will fill a city block in Cologne Germany. It is scheduled for completion in October 1992.

Acknowledgements

The authors wish to thank Dieter Jung for making it possible to carry out these experiments via a fellowship at the Kunsthochschule für Medien Köln. We also thank Dieter Jung, Urs Fries, Andy Pepper , Doris Vila, Stuart Rosenberg, Dan Plummer, and David Pizzanelli for insightful discussions regarding this work.

We are supported by a variety of different grants and sponsorships. These include grants from the University of New South Wales in Sydney, the Australian Network for Art and Technology, and a fellowship in Media Art at the Kunsthochschule für Medien Köln.

We thank the Shearwater Foundation of New York for supporting our appearance at this conference.

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