

Rochester Institute of Technology

RIT Digital Institutional Repository

Theses

1989

An anamorphic imaging model to correct geometric distortion in planar holographic stereograms

Michael Darwin Rainsdon

Follow this and additional works at: <https://repository.rit.edu/theses>

Recommended Citation

Rainsdon, Michael Darwin, "An anamorphic imaging model to correct geometric distortion in planar holographic stereograms" (1989). Thesis. Rochester Institute of Technology. Accessed from

This Thesis is brought to you for free and open access by the RIT Libraries. For more information, please contact repository@rit.edu.

Rochester Institute of Technology

An Anamorphic Imaging Model to Correct Geometric Distortion in Planar Holographic Stereograms

By

Michael Darwin Rainsdon

A thesis, submitted to

The Faculty of the School of Computer Science,

in partial fulfillment of the requirements for the degree of

Master of Science in Computer Science.

Approved by: _____

Dr. John R. Andrews

4/21/89
Date

Dr. Donald Kreher

21 April 1989
Date

Dr. Peter Anderson

21 April 89
Date

Acknowledgements

There are many people who have contributed to the completion of this work. Special thanks goes to my wife, Theresa, for her continual encouragement and support. To my children, Seth and Naomi, who were always happy to see me, even though I spent lots of nights working on this project. To Dr. John Andrews, my thesis advisor, for his direction, counseling, encouragement, and for making the actual holographic stereograms. To Dr. Donald Kreher, at RIT, for providing direction on the structure of this thesis. To Xerox Corporation for their financial backing, computer equipment, and release time which was given to this thesis.

To those mentioned above, and to the many unmentioned individuals who made this all possible, thank you. The journey has been worth the effort.

Abstract

This thesis demonstrates the importance of an accurate imaging model for making holographic stereograms by evaluating the geometric perspective distortion that is seen in flat holographic stereograms made using a circularly symmetric imaging model. A correct anamorphic imaging model for flat holographic stereograms is discussed and the limitations of the new model are explored. An implementation of the anamorphic imaging model as a computer system for creating geometric distortion-free holographic stereograms is described. Holographic stereograms were made using the computer system. A comparison is made of the uncorrected and corrected holographic stereograms. From viewing these holographic stereograms it is apparent that geometric distortion can be eliminated by using the correct anamorphic imaging model when creating holographic stereograms.

Table of Contents

Page #

1. Introduction and Background	1
1.1 Introduction	1
1.2 Definition of a Stereogram	2
1.2 Definition of a Hologram	2
1.2 Definition of a Holographic Stereogram	3
2. Theoretical Review of the Imaging Models	8
2.1 Imaging Models	8
2.2 Problems Using a Circularly Symmetric Projection Model	9
2.2.1 Distortion Along the x-axis	11
2.2.2 Distortion along the y-axis	15
3. The Anamorphic Imaging Model	19
4. The Holographic Frame Generation System (HFGS)	23
4.1 Explanation of the Correction Technique Used	23
4.2 Functional Specification	25
4.3 Architectural Design	26
4.4 Pseudo-code of Modules Used to Correct the Image Distortion	28
5. Conclusions	30
5.1 Problems Encountered and Solved	33
5.2 Current Shortfalls of the HFGS System	34
5.3 The Future and the HFGS System	34
6. References	37

1. Introduction and Background

1.1 Introduction

A holographic stereogram[1,2,3,4] is a recording of a three-dimensional scene consisting of a multitude of perspective views recorded sequentially using a holographic process. Although the perspective views recorded in a holographic stereogram can be any scene that can be photographed, in this discussion the perspective views are created by a computer using appropriate two-dimensional projections of a three-dimensional object [5]. A major problem associated with holographic stereograms is the geometric distortion[6,7,8,9] resulting from the differences in the circularly symmetric imaging model used in the computer calculations and the anamorphic imaging system created by horizontal parallax-only holographic stereograms. This thesis discusses the source of geometric perspective distortion and how it can be corrected by using an anamorphic imaging model that matches the imaging characteristics of the final holographic stereogram. A quantitative analysis of the perspective distortion resulting from the circularly symmetric imaging model will be presented and discussed. A computer system that implements a correct imaging model for a particular holographic stereogram geometry will be described. The computer system was developed and used to create a geometric distortion-free holographic stereogram. The corrected holographic stereogram was compared to one created from the same model using the circularly symmetric imaging model. The corrected holographic stereogram exhibited a geometrically accurate image of the three-dimensional model.

1.2 Definition of a Stereogram

A conventional stereogram is a pair of photographic images, i.e., two two-dimensional projections of a three-dimensional scene, taken from positions that correspond to the two eyes of an observer. The stereogram is viewed in such a way that each eye sees one of the two-dimensional images. The pair of two-dimensional views provides the human visual system with the appropriate information to perceive depth in the scene. The discrepancy in the two views is called horizontal parallax.

1.2 Definition of a Hologram

A hologram[10] is created by a recording process that stores, by the spatial distribution of fringes, a continuous range of perspective views over a limited viewing window specified by the recording geometry.

A hologram differs from a traditional photograph in three ways[11]:

- 1- No lens or other image-forming device is used. Since no lens is used each point on the object reflects light onto the entire photographic plate.
- 2- Coherent light, a laser, is used to illuminate the object. This light is called the object beam.
- 3- A portion of the coherent light is used to illuminate the photographic plate without striking the object first. This portion of the laser light is called the reference beam. Interference between the reference beam and the object beam creates fringes, which are the means of storing the image information.

1.2 Definition of a Holographic Stereogram

A holographic stereogram can be created by taking a series of perspective images and recording them on film using the holographic process.

A procedure for making a holographic stereogram is as follows:

- 1- Create the three-dimensional object in the computer.
- 2- Calculate the projection of the three-dimensional object on to the image plane from a single view point.
- 3- Vary the viewing location along the viewing vector and calculate the projection of the object onto the image plane many times, i.e., 50 - 1000 (see Figure 1).

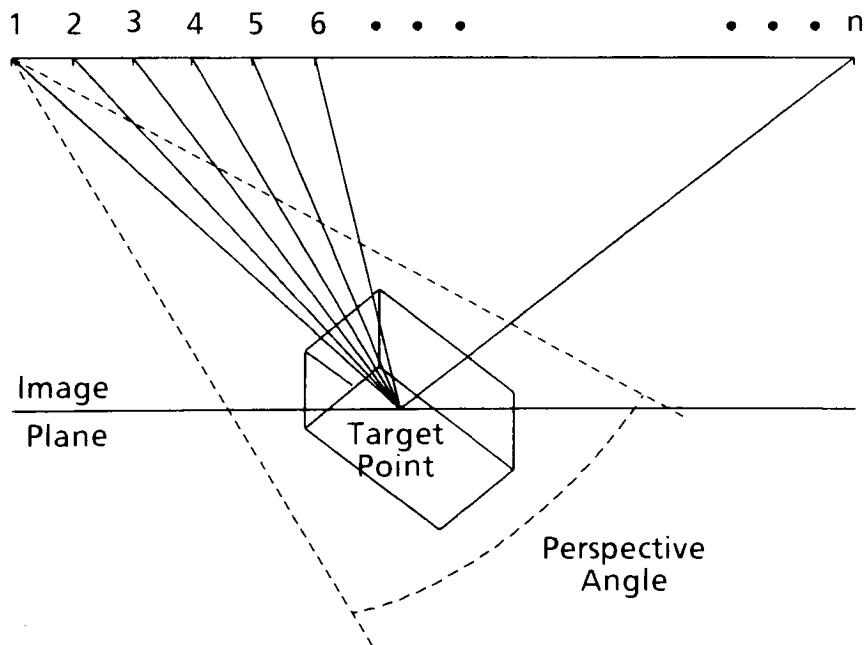


Figure 1

An image is generated for each of the eye points 1 - n by projecting the 3-dimensional model onto the image plane.

4- Photograph each computed projection in sequence.

5- Illuminate an image of each of the above photographically recorded projections with a laser and project them onto a diffusing screen. The scattered light from the image-bearing diffusing screen and the reference beam simultaneously illuminate small vertical strips of the photographic plate (see Figure 2). Each small vertical strip is called a slit hologram (see Figure 3).

6- After chemical development and bleaching, the master hologram is illuminated with the reference beam and a three-dimensional virtual image will be reconstructed (Figure 4).

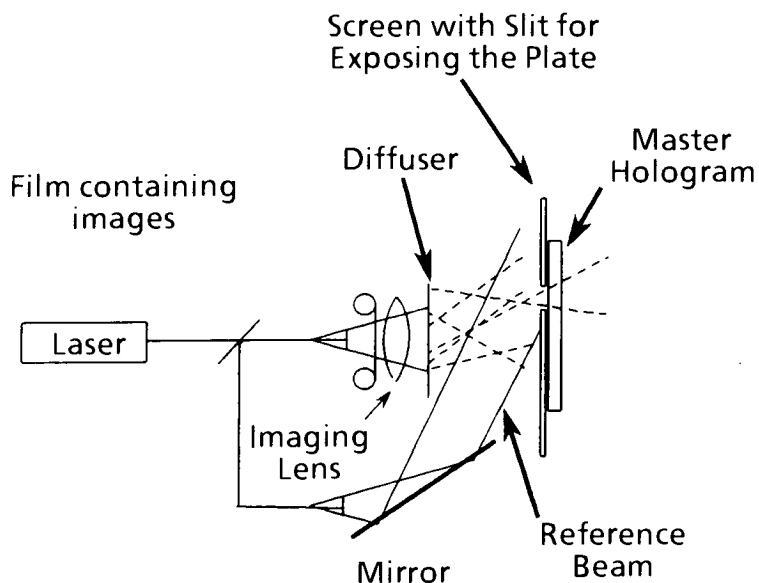


Figure 2

Diagram of setup for creating the Master Hologram. Each image is recorded as a slit hologram on the Master Hologram.

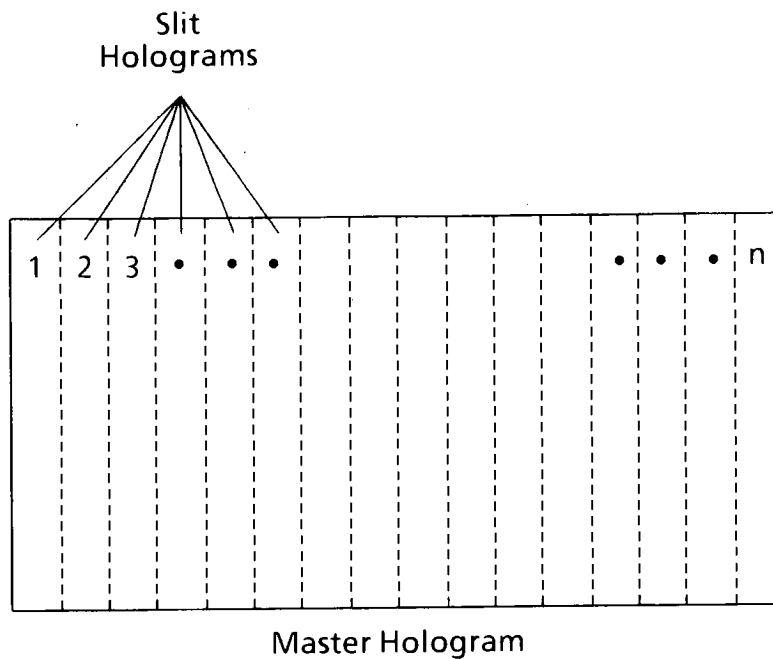


Figure 3

This figure shows the relationship between the Master Hologram and the Slit Holograms. Each Slit Hologram represents a single perspective image, and corresponds to eye points 1 - n.

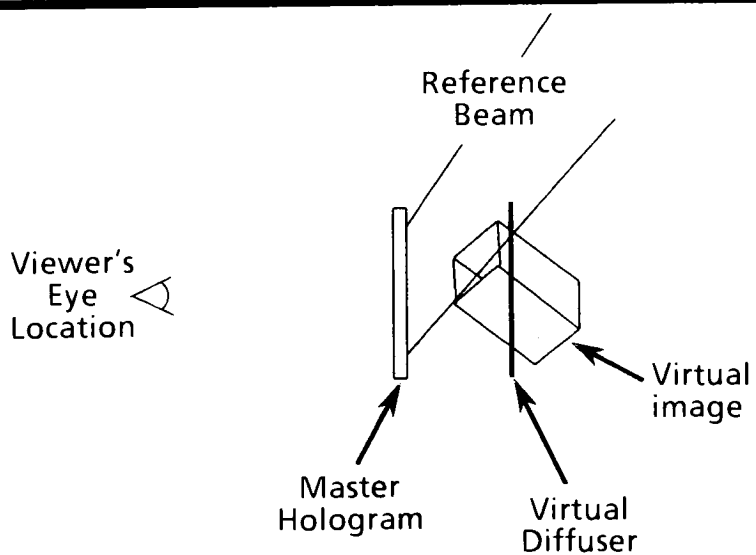


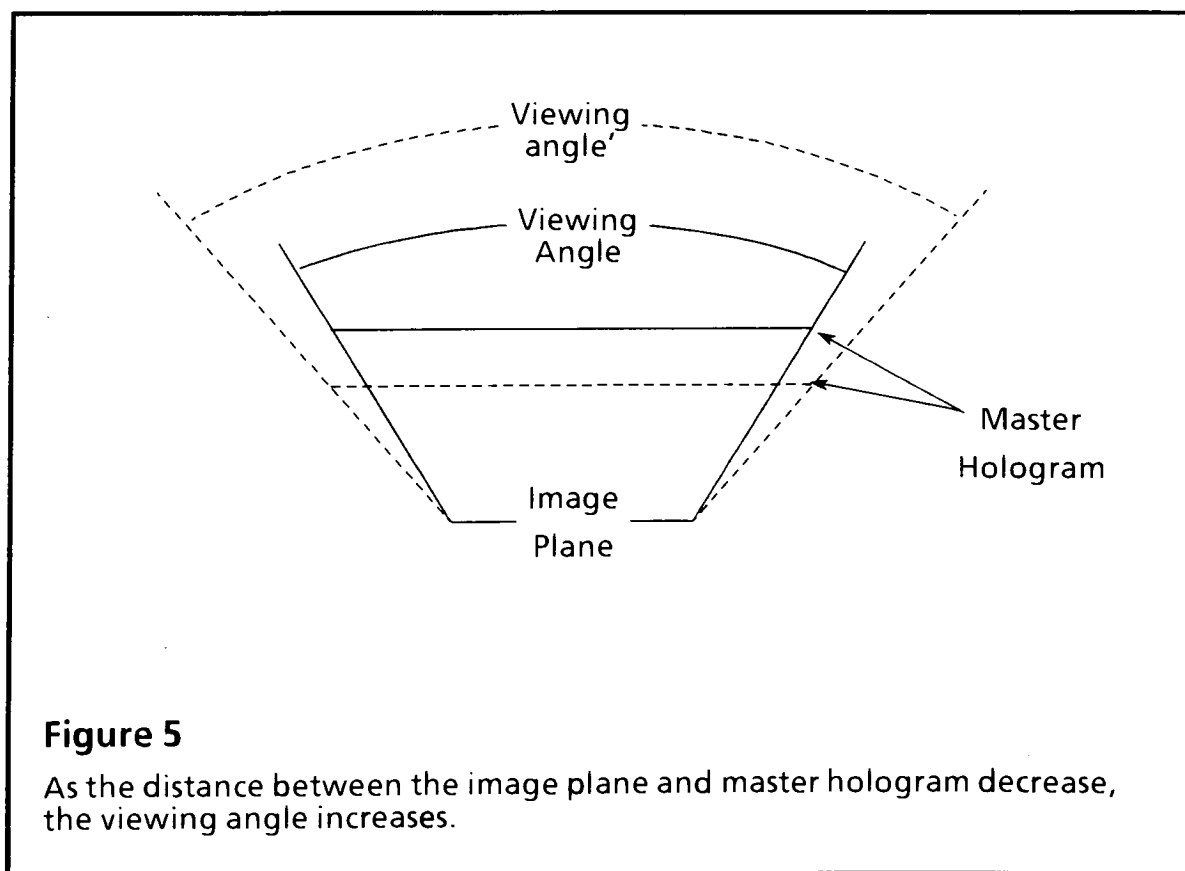
Figure 4

Diagram showing the viewing of the Master Hologram.

This process can be used to create a hologram of three-dimensional data stored in a computer. It accomplishes this by creating a set of two-dimensional projections of the three-dimensional objects stored in a computer using computer algorithms. The projections are generated for a number of view points. When the projections are incorporated in the holographic stereogram, each eye sees different images corresponding to the parallax of a normal scene. Since a large number of views are included, the viewer can move within the viewing window and maintain natural parallax, consequently seeing a virtual image that has the depth cues of the real object. When the view points change only along the horizontal axis, then a "horizontal parallax-only" holographic stereogram is created. In this work the discussion will be restricted to the horizontal parallax-only holographic stereograms. However it is possible to incorporate a range of views that corresponds to changes in the vertical viewing locations as well, resulting in a full parallax holographic stereogram. The correction techniques that are described below for horizontal parallax-only holographic stereograms can be readily extended to full parallax holographic stereograms.

The master holographic stereogram can be thought of as a viewing window. The image is only visible when vectors from the viewer's eyes to the object pass through the master hologram. When the master hologram is located at the intended viewing location, then the circularly symmetric imaging model is appropriate. Like a window in a house, the size and viewing angle of any object behind, or in front of, the window depends on how close the object is to that window. As the object moves closer to the window the viewing angle increases.

It is usually desirable to have a wide viewing angle. This angle is determined by the size of the photographic plate used to make the master hologram, the size of the object, and the distance between the master hologram and the image plane. The size of the holographic plate and the size of the image plane are constants based on the holographic imaging process used. Therefore, to increase the viewing angle, the distance between the viewing window and the object needs to be small relative to the size of the object (Figure 5). When the intended viewing location is far from the master hologram, as is required for obtaining a wide viewing angle, the circularly symmetric imaging model is no longer appropriate.



2. Theoretical Review of the Imaging Models

2.1 Imaging Models

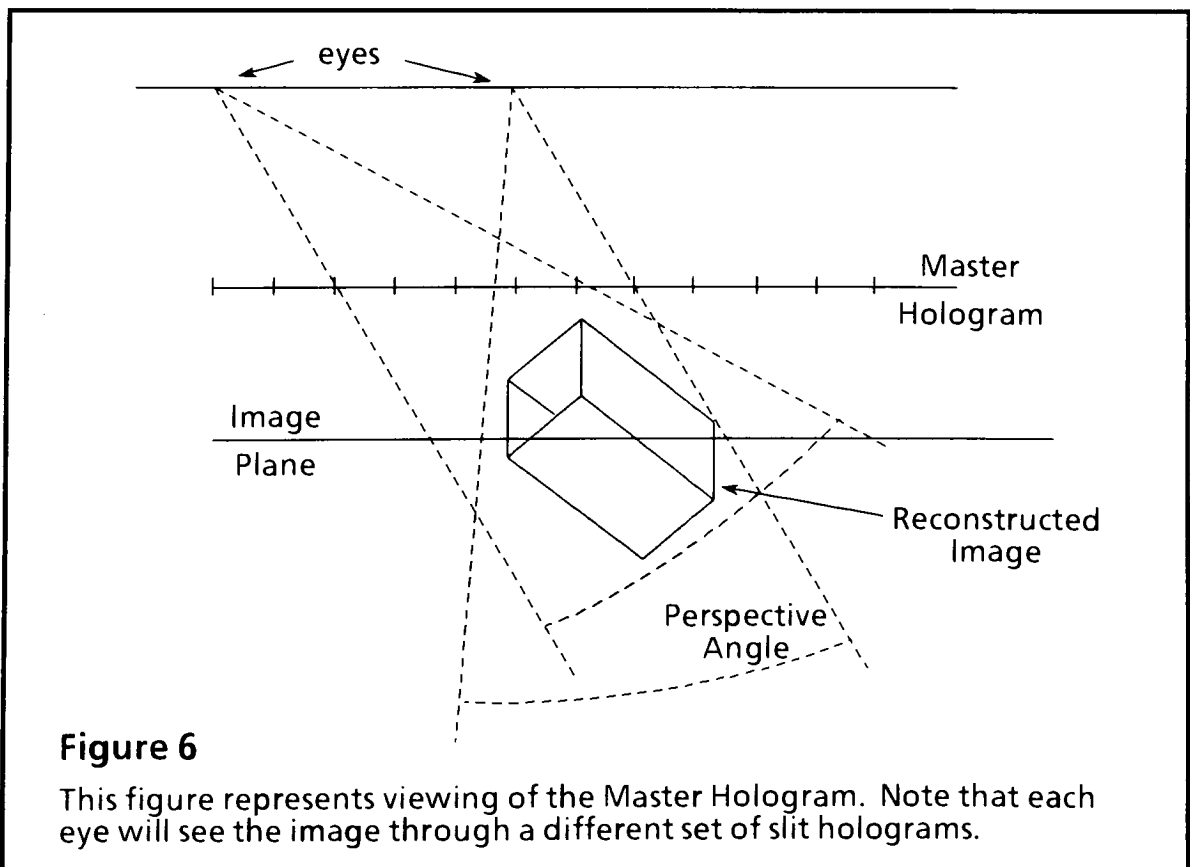
The human eye and other imaging systems such as cameras view the world with a circularly symmetric imaging system. Holographic stereograms, because they only have parallax in one direction, are anamorphic imaging systems. Therefore, if we apply a circularly symmetric imaging model to holographic stereograms the virtual image will exhibit geometric distortion. The circularly symmetric imaging model is the imaging model generally available in computer graphics imaging software. This model is, also, the most often used imaging model for making holographic stereograms. An understanding of the differences in the two imaging systems is useful in determining the amount of distortion created when using the circularly symmetric imaging model to make holographic stereograms.

The fundamental concept to remember when creating holographic stereograms is that the imaging model used while creating the two-dimensional perspective images needs to be the same imaging system that is created in the formation of the holographic stereogram.

Part of the implementation of this concept requires that the image plane remain stationary during the creation of all the perspective images. The reason for this is that a virtual image is created as the viewer looks at the flat master hologram. If the image plane were allowed to remain perpendicular to the "eye-point-to-target-point" vector it would require a very complex imaging system to be used during the creation of the master hologram, or additional distortion would be introduced into the hologram.

2.2 Problems Using a Circularly Symmetric Projection Model

Perspective distortion occurs when the monocular image viewed by the observer is made up of more than one slit hologram (see Figure 6). This occurs when the viewer is located anywhere but in the plane of the master hologram. Because of the desire to have a large viewing angle, the distance from the master hologram to the image plane is kept small. To view most images close is not convenient. It is more desirable to view the image from a normal viewing distance, i.e., some distance away from the master hologram. The distance between the master hologram and the viewer's location causes the viewer to see an image that is a composite, containing portions of views from many different eye points (Figure 6). Thus, the viewer sees a distorted image. Geometric



distortion in circular holographic stereograms has been previously described in the literature [6,7,8].

In holographic stereograms each slit hologram contains a single image of the diffuser with the two-dimensional image projected onto it (Figure 2).

If one had a holographic stereogram made of a single slit hologram, the viewer would need to move along the line represented by the eye points to actually see the entire image (Figure 7). At any one time the viewer would only be able to see that portion of the image that could have been seen through the slit when the slit hologram was being exposed.

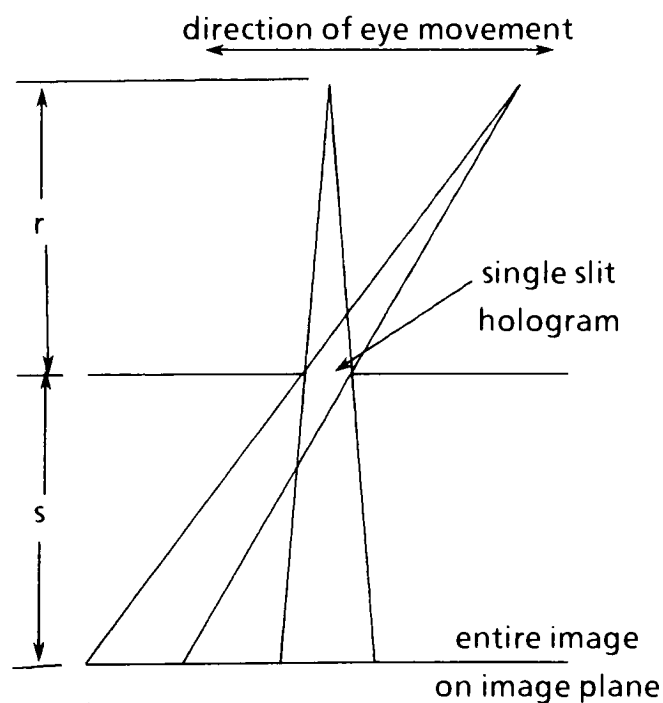


Figure 7

A single slit hologram contains the entire perspective image from a single eye point. The location of the viewer's eye point determines the portion of the image seen by the viewer at any given time.

2.2.1 Distortion Along the x-axis

In our discussion of distortion in holographic stereograms, we describe the distortion seen along the x-axis and along the y-axis of a holographic stereogram separately. The reason for this is that in horizontal parallax-only holographic stereograms the type of distortion seen along the x-axis is different than that seen along the y-axis.

To understand the perspective distortion, along the x-axis, in holographic stereograms made from images created using a circularly symmetric imaging model, refer to the projection models in Figure 8.

Figure 8a represents the circularly symmetric projection model for projecting point P onto the image plane at $IP_{(x)}$ from the viewing location VP . If this model is used to project a three-dimensional object onto the image plane, and then viewed, it would allow the viewer to see a virtual monocular image of the three-dimensional object as if the object were really there; assuming that the viewing and projection eye points were in the same location. The model in Figure 8a shows the correct image plane projection ($IP_{(x)}$), of point P , when viewing the real object.

Figure 8b represents the projection geometry recorded on a holographic stereogram for the projection of point P onto the image plane at $IP'_{(x)}$ from the viewing location VP . VP is the viewing location, EP is the eye point used to project point P onto the image plane, Hv is the location of the slit hologram that contains the projected image from EP , and TP is the target point used during image creation. The model in Figure 8b shows the holographic stereogram

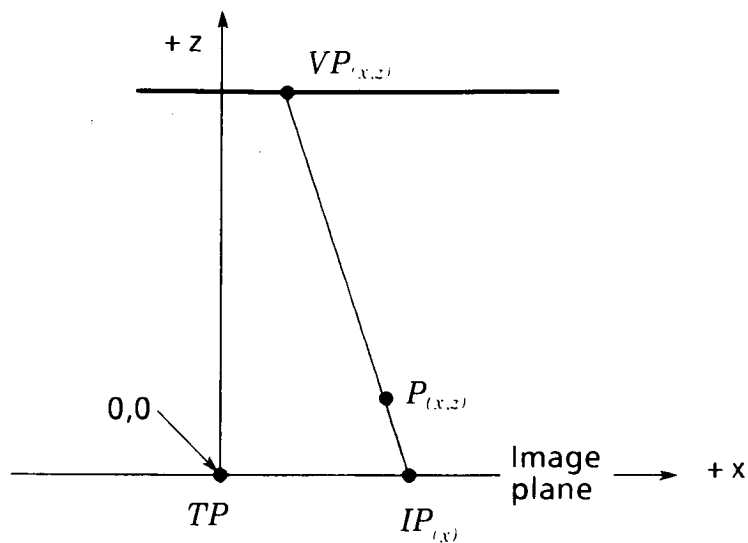


Figure 8a

Diagram of a circularly symmetric projection model. Where VP is the viewing point, TP is the target point, P is the image point, and $IP_{(x)}$ is the projected location of point P on to the image plane.

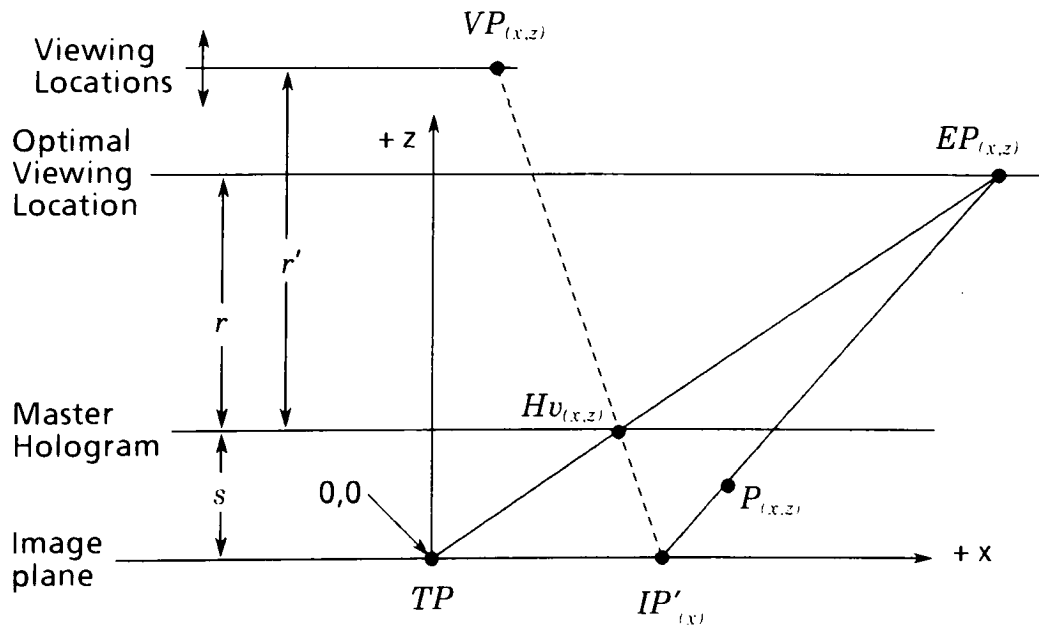


Figure 8b

Diagram representing distortion resulting from viewing point P as seen through slit hologram Hv . EP is the eye point that slit hologram Hv was projected from. Point $IP'_{(x)}$ is the points where point P appears on the image plane.

projection of point P onto the image plane ($IP'_{(x)}$) when viewing the holographic stereogram.

The point $IP_{(x)}$ is the intersection of the vector $VP-P$ with the image plane. The point $IP'_{(x)}$ is the intersection of the vector $EP-P$ with the image plane. Since $IP_{(x)}$ defines the real projection of point P onto the image plane and $IP'_{(x)}$ defines the virtual projection of point P onto the image plane through the holographic stereogram, the x-axis distortion created in the holographic stereograms can be measured by comparing these two values.

To find $IP_{(x)}$ we determine where the vector $VP-P$ intersects the image plane. This is defined as:

$$IP_{(x)} = VP_{(x)} + \left| \frac{(P_{(x)} - VP_{(x)}) * VP_{(z)}}{(VP_{(z)} - P_{(z)})} \right|$$

To find $IP'_{(x)}$ we determine where the vector $EP-P$ intersects the image plane. This is defined as:

$$IP'_{(x)} = EP_{(x)} - \left| \frac{(EP_{(x)} - P_{(x)}) * EP_{(z)}}{(EP_{(z)} - P_{(z)})} \right|$$

To solve the above equation ($IP'_{(x)}$) we need to first find the location of the image projection eye point EP . EP is defined as the intersection of the vector formed by the original image projection eye points and the vector $TP-Hv$. EP is given by:

$$EP_{(x)} = \frac{\left\{ \left| \frac{(IP'_{(x)} - VP_{(x)}) * (VP_{(z)} - Hv_{(z)})}{VP_{(z)}} \right| + VP_{(x)} \right\} * EP_{(z)}}{Hv_{(z)}}$$

Now substituting the above equation ($EP_{(x)}$) into the above equation ($IP'_{(x)}$) we get:

$$IP'_{(x)} = \frac{\left[\frac{P_{(x)} * EP_{(z)}}{EP_{(z)} - P_{(z)}} \right] + \frac{VP_{(x)} * EP_{(z)}}{Hv_{(z)}} * \left\{ 1 + \left[\frac{EP_{(z)} * (VP_{(z)} - Hv_{(z)})}{VP_{(z)} * (EP_{(z)} - P_{(z)})} \right] - \left[\frac{VP_{(z)} - Hv_{(z)}}{VP_{(z)}} \right] - \left[\frac{EP_{(z)}}{EP_{(z)} - P_{(z)}} \right] \right\}}{1 - \left[\frac{EP_{(z)} * (VP_{(z)} - Hv_{(z)})}{Hv_{(z)} * VP_{(z)}} \right] + \left[\frac{EP_{(z)}^2 * (VP_{(z)} - Hv_{(z)})}{Hv_{(z)} * VP_{(z)} * (EP_{(z)} - P_{(z)})} \right]}$$

A normalized distortion along the x-axis of the holographic stereogram can be defined as:

$$\%error_{(x)} = \left| \left(\frac{IP'_{(x)}}{IP_{(x)}} \right) - 1 \right| * 100$$

where $\%error_{(x)}$ is the amount of distortion seen ($IP'_{(x)}$) in relation to what the viewer should see ($IP_{(x)}$).

If the above equations are simplified by constraining $VP_{(x)}$ to be equal to $TP_{(x)}$, i.e., 0, and $VP_{(z)}$ to be equal to $EP_{(z)}$, then a family of curves, Figure 9, can be generated by varying the ratio r/s . The z-axis distance from the master hologram to the eye point vector ($EP_{(z)} - Hv_{(z)}$) is r , and the z-axis distance from the image plane to the master hologram ($Hv_{(z)}$) is s . Varying this parameter shows how the magnitude of the distortion depends on the recording geometry. These curves represent the x-axis distortion seen in holographic stereograms when viewed from a viewing location of $(0, EP_{(z)})$, and varying the location of point P .

Note that when calculating the $\%error$ the x-component of point P cancels out of the equation, leaving the z-component of point P as the only independent variable in the equation. This means that each curve represents the x-axis distortion as point P moves anywhere within model space.

If we then constrain r/s and let $VP_{(z)}$ vary we get a second family of curves for each value of r/s . These curves, Figure 10, show the x-axis distortion seen in holographic stereograms when the viewer is allowed to move in and out from the optimal viewing location. In Figure 10 we use r' to represent $VP_{(z)}$.

Figures 9 and 10 show the amount of x-axis distortion in relation to how far point P is from the image plane when viewing a holographic stereogram. The x-axis in these figures is the distance point P is from the image plane normalized with respect to the distance from the image plane to the master hologram ($[(P_{(z)} / Hv_{(z)}) - 1]$).

Several items can be seen from Figure 9. Holographic stereograms created from circularly symmetric projection images should exhibit no distortion when the objects are on the image plane. They should make objects in front of the image plane appear smaller the closer they are to the viewer, and objects behind the image plane should appear larger the farther they are from the viewer.

Figure 10 shows the amount of distortion seen as the viewer moves closer or farther away from the optimum viewing location for a value of r/s equal to 2. The curves change slightly when the viewer moves away from the preferred viewing location. The amount of distortion seen in both Figures 9 and 10 gets progressively larger as point P moves away from the image plane. Larger values of r/s , which give a wider viewing angle in the final hologram, also lead to larger distortions.

2.2.2 Distortion along the y-axis

There is no perspective distortion along the y-axis of the holographic stereogram as long as the hologram is viewed from the optimal viewing distance.

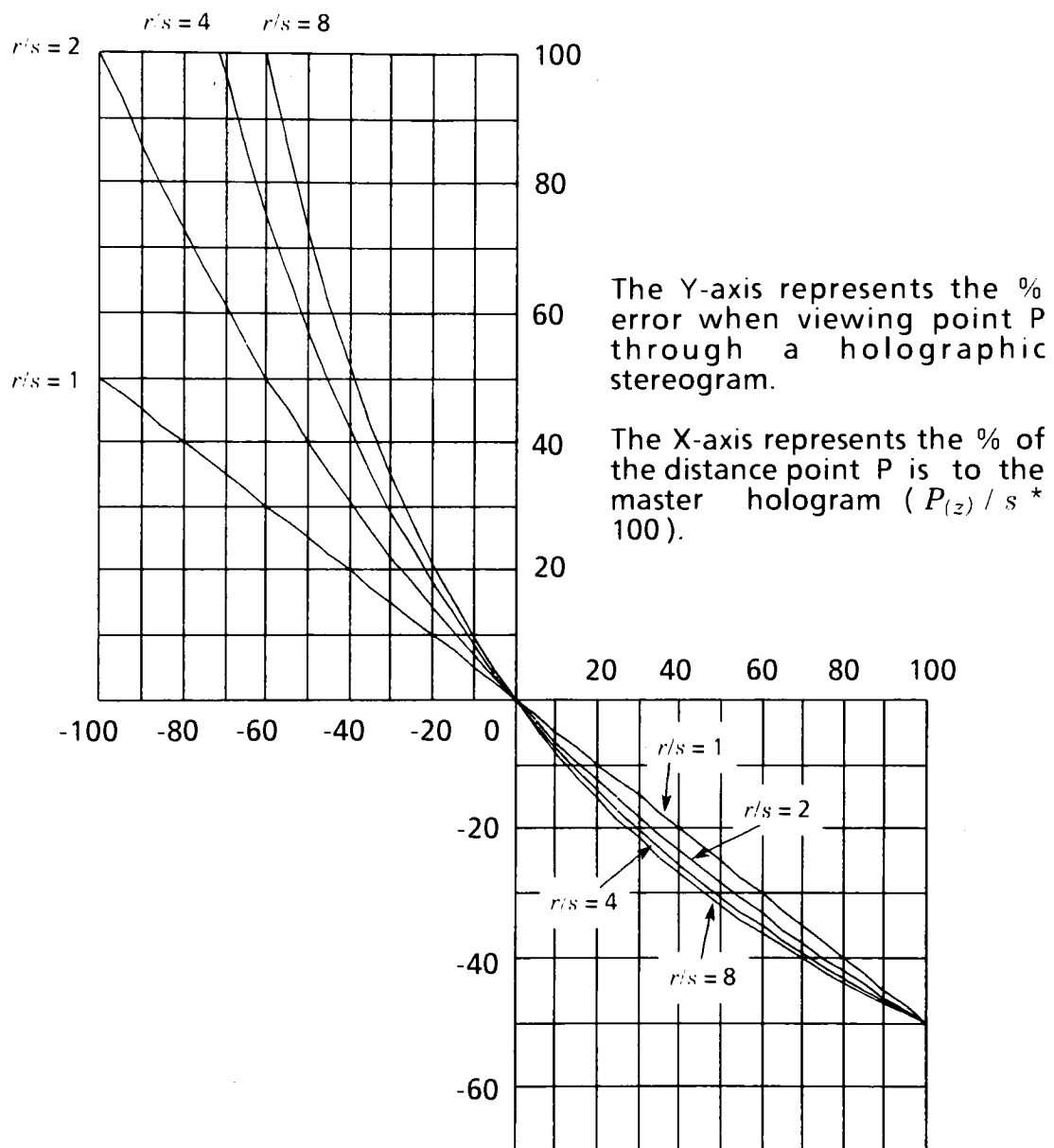


Figure 9

These curves represent the amount of geometric distortion in a holographic stereogram when the perspective images are created using a circularly symmetric imaging model. The several curves represent the amount of distortion for various values of r/s . These curves assume the viewer is viewing the hologram from the point $(TP_{(x)}, EP_{(z)})$.

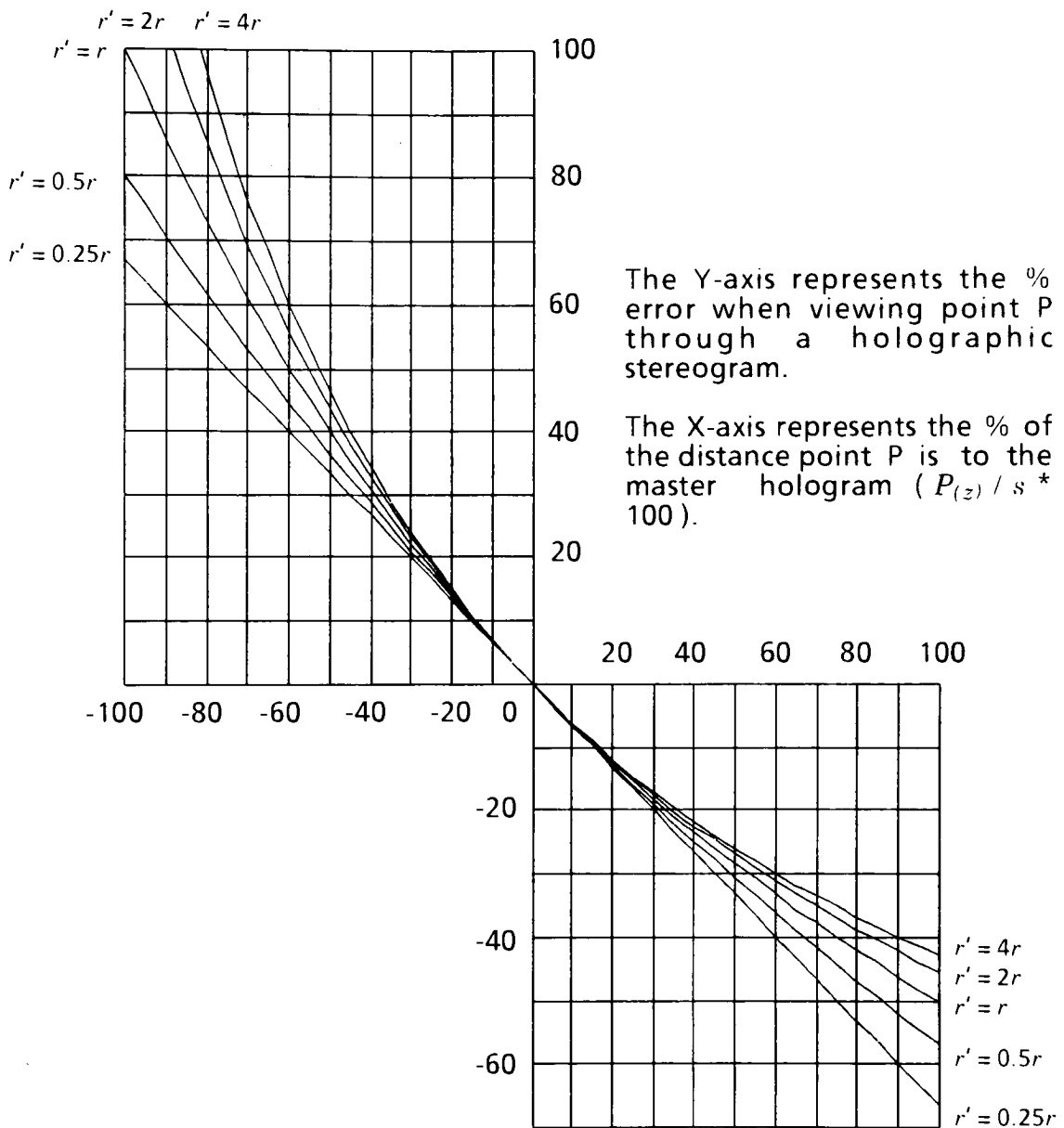


Figure 10

These curves represent the amount of geometric distortion in a holographic stereogram when the perspective images are created using a circularly symmetric imaging model. The several curves represent the amount of distortion for a value of $r/s = 2$, and various values of r' . Varying values of r' mean that the viewer is viewing the hologram from different viewing distances than those used when creating the perspective images.

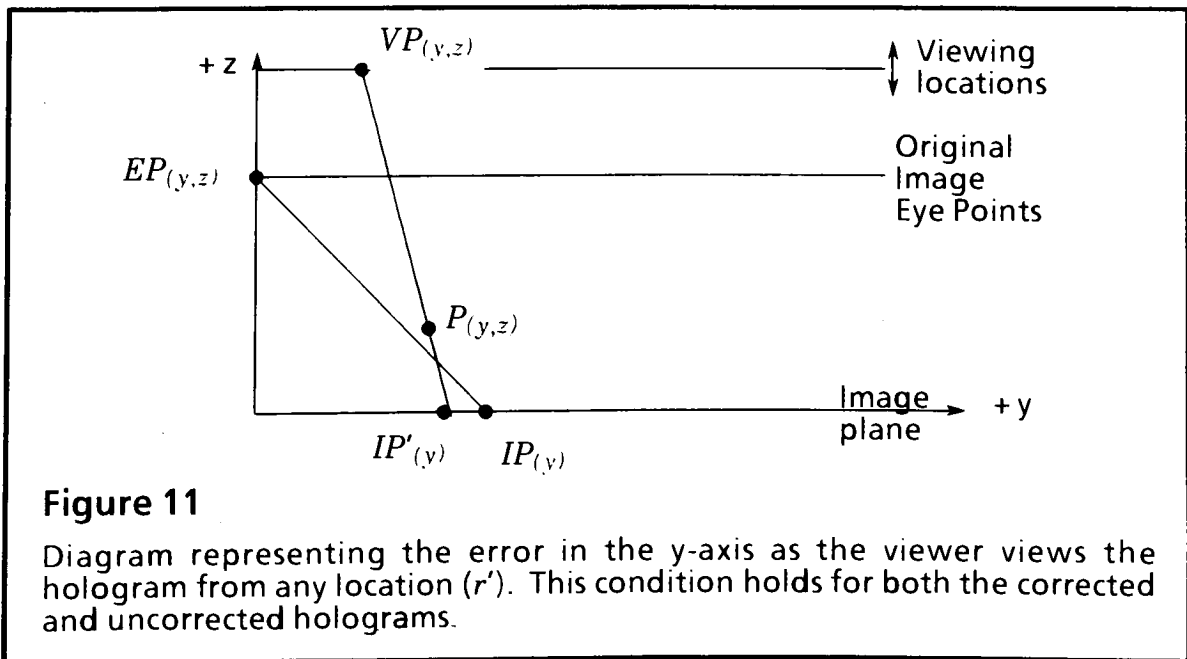
The perspective distortion along the y-axis of the hologram as the viewer moves closer or farther away from the optimum viewing distance (Figure 11) is given by the following equations:

$$IP_{(y)} = VP_{(y)} + \left| \frac{(P_{(y)} - VP_{(y)}) * VP_{(z)}}{VP_{(z)} - P_{(z)}} \right|$$

$$IP'_{(y)} = \frac{P_{(y)} * EP_{(z)}}{EP_{(z)} - P_{(z)}}$$

where $P_{(y)}$ and $P_{(z)}$ are the y and z coordinate of point P , $IP_{(y)}$ is the y-value of point P projected onto the image plane from the viewing location VP , and $IP'_{(y)}$ is the y-value of point P as seen through the hologram from the viewing location EP . EP is the projection eye point, and VP is the viewing location.

The distortion in the y-axis is the same for both the uncorrected and the corrected holograms when only horizontal parallax is included in the holographic stereogram. The only viewing location where there is no distortion in the y-axis is when the hologram is viewed from the viewing plane, or point P is on the image plane.



3. The Anamorphic Imaging Model

The type of perspective projection model needed for creating images for use in making holographic stereograms is one that imitates the illumination of a single slit hologram and the virtual image that can be viewed through it. Remember that a single slit hologram contains a complete recording of a two-dimensional projection of the three-dimensional model, but the image can only be viewed by looking through the slit hologram (Figure 7). Also keep in mind that the image plane remains stationary during the creation of all the two-dimensional projections.

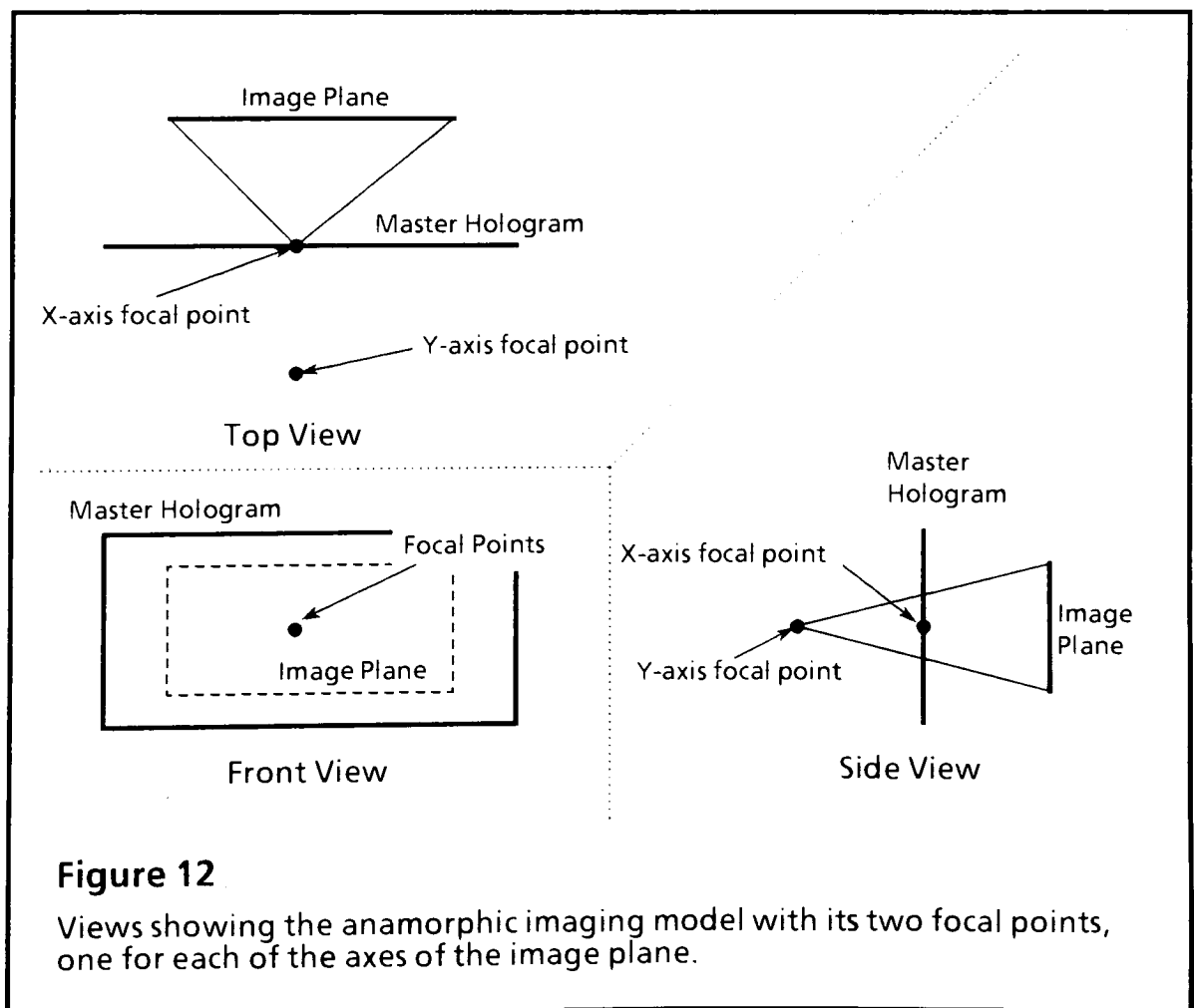
From a close examination of Figure 7 one sees that the correct imaging system for a slit hologram has two different focal points, one for the horizontal axis and one for the vertical axis. Figure 12 shows these two focal points. Note that the focal point for the x-axis is at the master hologram. This means that the slit hologram and the projection focal point for the x-axis are in the same location. It can, also, be seen that the circularly symmetric imaging model is appropriate when the master hologram is located at the intended viewing location.

To evaluate the distortion seen in this anamorphic imaging model, we create a slit hologram Hv of point P (Figure 13). Using this new imaging system we find that point P is projected onto the image plane along vector $Hv-P$. If we call the projection of point P onto the image plane $IP_{(x)}$, and then create and illuminate the slit hologram, we find that point $IP_{(x)}$ is viewed by the viewer along vector $Hv-IP_{(x)}$. By inspection it can be seen that vector $Hv-IP_{(x)}$ is exactly the vector $Hv-P$, which means that the viewer sees point P exactly where it should be. Therefore, no distortion is seen in the reconstructed image. Also note

that no matter where the viewer is located along the vector $Hv-P$ the image of point P appears in its correct x-axis position.

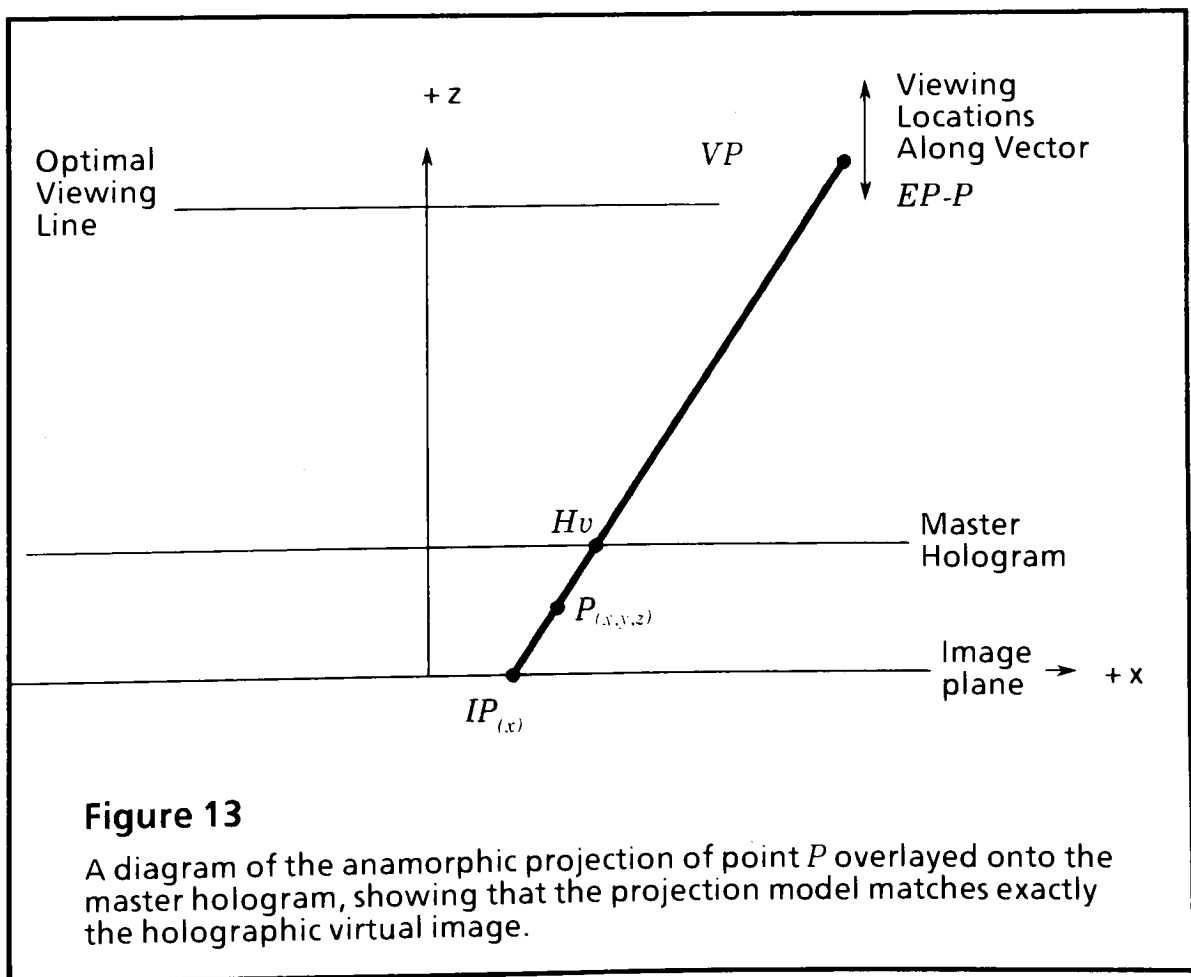
This new imaging model corrects perspective distortion along the x-axis. As mentioned earlier, distortion in the y-axis will still occur as the viewer moves away from the optimal viewing plane from which the perspective frames were created.

Several authors have discussed ways of correcting geometric distortion in holographic stereograms. One approach requires modifying the optical system used to create the hologram [6,12,13,14]. Another approach uses a photographic



printing process to rearrange the two-dimensional projections [6]. These techniques were for correcting distortion in circular holographic stereograms.

Two additional methods for correcting geometric distortion in holographic stereograms are described in the literature that correct the distortion in a computer model before the images are photographed. One approach is to modify an existing computer graphics image projection software so that the two-dimensional projections fit the anamorphic imaging model of the holographic stereogram [15]. Another approach uses the images as they are generated by existing computer graphics packages, and then modifies these images by slicing them into strips and rearranging the strips into new images [6]. Both these



approaches create the appropriate images as long as the number of strips used is large, i.e., > 100 .

An evaluation of the above two approaches, for correcting geometric distortion in holographic stereograms created from computer generated images, yields the following conclusions[16]:

Cutting the perspective images into strips and rearranging them into new images has the following characteristics:

- The original images can be generated by any means, i.e., existing image projection software.
- The software that creates the original image must be able to control the image plane location and size.
- This technique requires generating two sets of images.
- The second set of images can be recorded as they are created.
- This technique allows for the incorporation of motion into the hologram.

Incorporating the anamorphic imaging model into existing imaging software has the following characteristics:

- This technique is relatively easy to implement into ray trace imaging software.
- The software must be able to control the image plane location and size.
- Only one set of images is created.
- The images can be recorded as they are created.
- There is a possibility of saving computer time and storage.
- This technique does not allow for the incorporation of motion into the hologram.

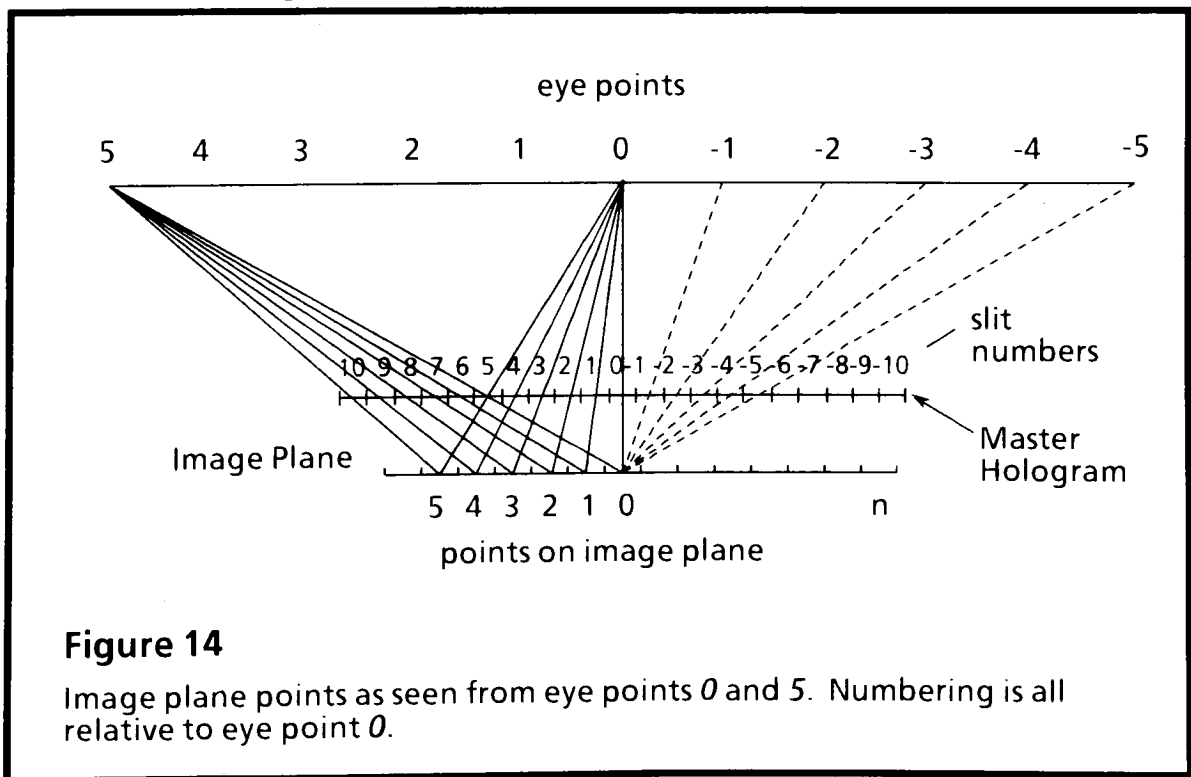
4. The Holographic Frame Generation System (HFGS)

4.1 Explanation of the Correction Technique Used

Because of the desire to use existing computer graphics software and hardware in creating the images, the approach of slicing the images and rearranging the slices was used.

This method of correcting distortion consists of slicing each image into n equal-width pieces and then creating another set of images by appropriately distributing the slices into the new images. A property of holographic stereograms that allows this slicing of images to correct for distortion is that each slit hologram stores the entire image of the object as seen through that particular slit.(see Figure 7)

Observe in Figure 14 that at eye point 0, image point 0 is seen through slit



hologram 0, as it should be. Also, observe that image point 5 is seen through slit hologram 5 instead of slit hologram 0. This means that image point 5, as seen from eye point 0, is really the point as projected from eye point 5. This is what causes geometric distortion.

To correct this distortion, we split image 0 into n equal sized strips (the value n is the number of slit holograms on the image plane). Then these strips are distributed among the new images so that the viewer sees, from eye point 0, the image as taken from eye point 0. For example, image point 5, as seen from eye point 0, should be the 5th strip over and it should reside in slit hologram number 5. Figure 15 shows the distribution of the original images into the new images.

While implementing this technique using the existing capabilities of a computer graphics system, two additional capabilities were required: 1) the

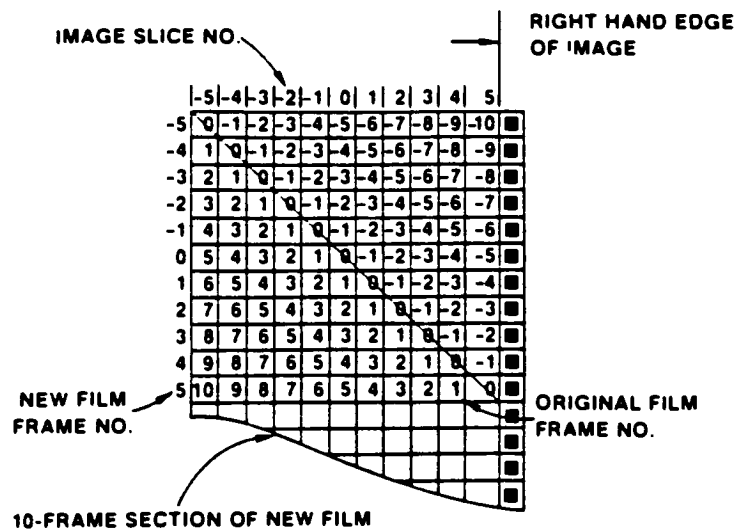


Figure 15

Scheme for synthesizing the corrected images from the original images[6].

capability of slicing each image into equal size strips, and 2) the capability of rearranging these strips into a new set of images. Then the whole set of software had to be packaged into a user environment that was functional.

4.2 Functional Specification

The HFGS system provides an interface for creating 24-bit color Run Length Encoded (RLE) raster images from three-dimensional models. These raster images are used in creating geometric distortion-free planar holographic stereograms. The data format of the three-dimensional models used in this system is Intergraph Corporation's IGDS file format.

Intergraph Corporation's ModelView software product is required to run this system. ModelView is the software system that creates the original images from the three-dimensional model.

The system was designed as a prototype system, intended for use in researching holographic stereograms. Its intended users are researchers who understand the holographic stereogram process and the HFGS system. It was also designed assuming that the users would know the IGDS three-dimensional modeling system and how to use the ModelView product.

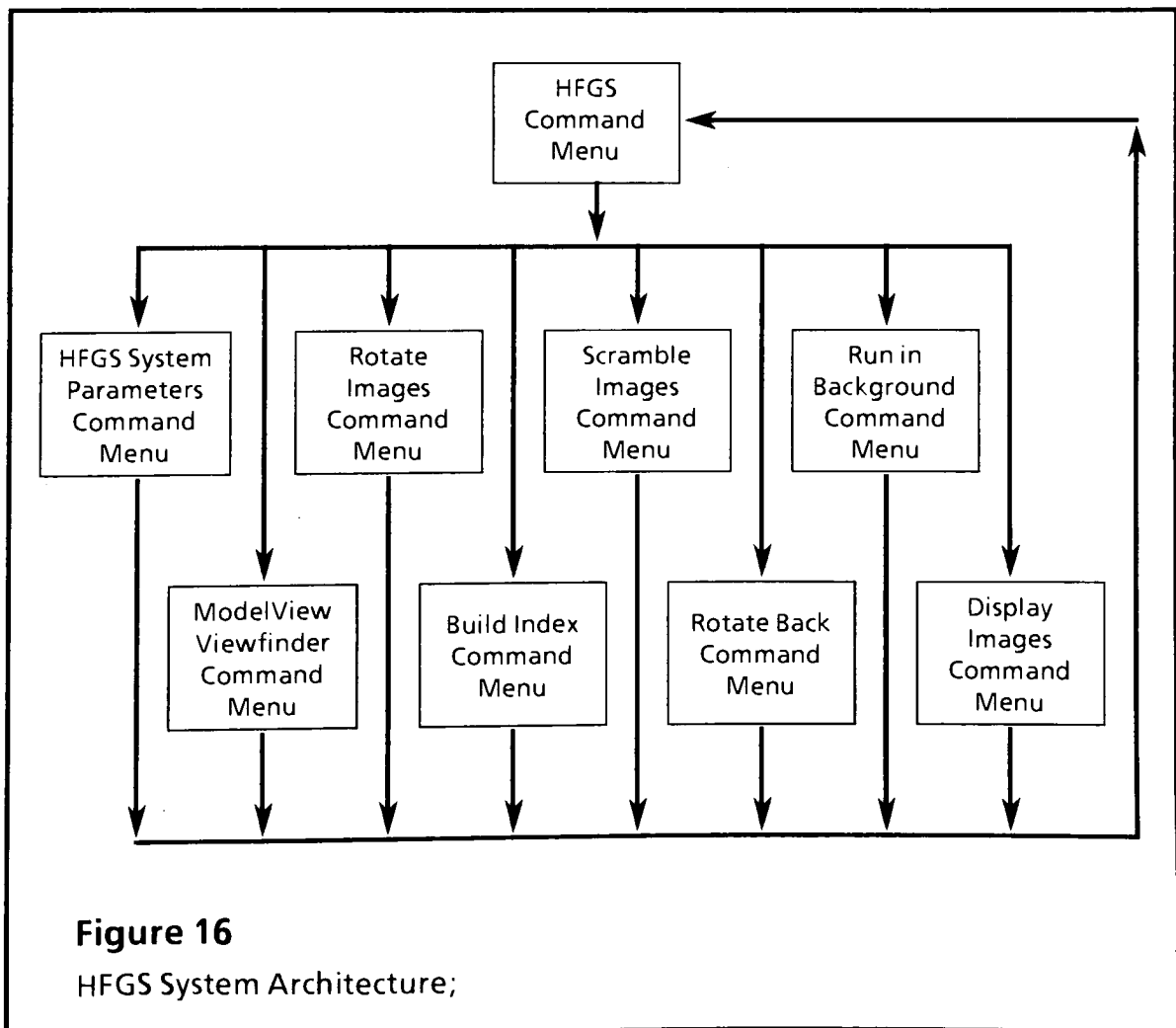
The HFGS system provides the user with a screen menu oriented interface, with key-in and point-and-click options. All the options can also be run from a UNIX command line environment.

An important consideration when running the HFGS system is the amount of on line disk space required. The size of a 793 x 592 RLE raster image is about 0.4 megabytes. To achieve a good holographic stereogram, approximately 550 original images are required, as well as approximately 200 final images. This equates to a peak on line disk memory requirement of approximately 300 megabytes for one holographic stereogram. Note that after the images are processed the original images can be discarded, leaving approximately 80 megabytes of data.

Because of the amount of data being processed the user should be sure that the three-dimensional model and HFGS System Parameters are correct, and the file space is available before executing each step in the process.

4.3 Architectural Design

The HFGS system was designed in a modular fashion. This enables the individual modules to be changed at will without affecting the entire system. The actual system architecture is defined in the diagram in Figure 16. The data flow of the system is defined in Figure 17.



4.4 Pseudo-code of Modules Used to Correct the Image Distortion

Listed below is the pseudo-code for the critical modules of the system. The modules below are all that is actually required to do the distortion correction. The other modules in the system are useful as a user interface only, therefore their code is not defined here.

Rotate Image Command

```
{
for number of frames
{
    create red, green, and blue color arrays to represent the pixel array of the
        image file.
    read, and expand the run length encoded (RLE) image file into memory so
        that each pixel is represented by three bytes ( one byte in each of the
        red, green, blue (RGB) color arrays).
    write the RGB arrays back out starting at the bottom of the first column
        and indexing up the column. The output format is RLE.
    }
}
```

Build Index Command

```
{
for number __ of __ frames
{
    open file.
    read header.
    write byte offset record to index 1 array.
    lines per slot = number of lines in image / number of slots.
    for number of lines in image
    {
        read lines per slot lines.
        write byte offset record to index 1 array.
    }
    close file.
}
number of final images = number of images - number of slots.
for number of final images
{
    for number of slots
    {
        read image file, slot number, and byte offset from index 1
            and write it to index 2 array.
    }
}
create index 2 file.
write index 2 to file.
close index 2 file.
}
```

Scramble Image Command

```
{
for number of final frames
{
    create final image file.
    write image header to final image file.
    for number of slots
    {
        read record from index 2 ( image file number, byte offset to start
            of slot, and number of bytes in slot.
        open image file.
        index by byte offset.
        read number of bytes into memory.
        write number of bytes to final image file.
    }
    close final image file.
}
}
```

Rotate Back Image Command

```
{
for number of frames
{
    create red, green, and blue color arrays to represent the pixel array of the
        image file.
    read, and expand the run length encoded (RLE) image file into memory so
        that each pixel is represented by three bytes ( one byte in each of the
        RGB color arrays).
    write the RGB arrays back out starting at the top of the last column
        and indexing down the column. The output format is RLE.
}
}
```

5. Conclusions

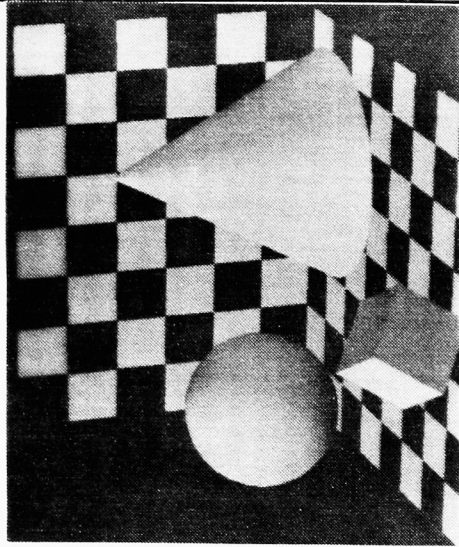
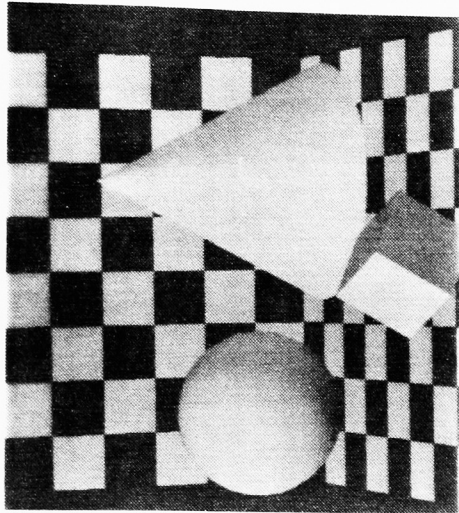
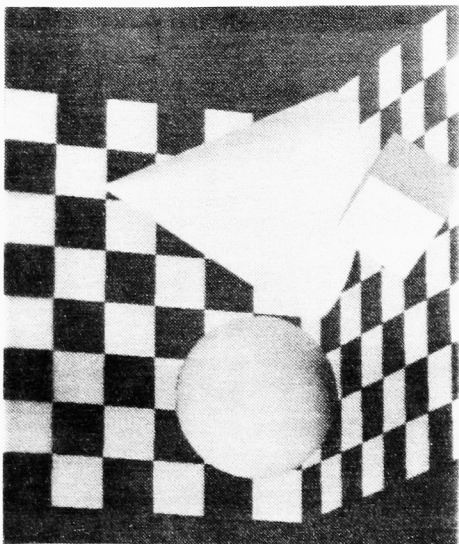
The test holograms were created from photographs of the original and corrected images by Dr. John R. Andrews, Webster Research Center, Xerox Corporation.

Figures 18 and 19 show photographs of the corrected and uncorrected holograms along with the corresponding perspective views of the test model. As can be seen, the corrected model maintains true size, shape, and orientation with respect to itself and the real world around it from the different viewing angles. Also note the geometric distortion exhibited in the uncorrected hologram in relation to what the graphs in Figures 9 and 10 show.

If one refers to the distortion graph in Figure 9, it can be noted that the uncorrected hologram should exhibit distortion that changes sign at the image plane and that the magnitude of the distortion increases the farther the objects get from the image plane. It can also be seen that the objects in front of the image plane appear smaller than they should, and the objects behind the image plane appear larger than they should.

The HFGS system was used to create a set of corrected and uncorrected images of objects on the image plane. The uncorrected images matched exactly the corrected images, showing that objects on the image plane will exhibit no geometric distortion in either the corrected or uncorrected holograms. While viewing the corrected hologram, the x-axis distortion is illuminated no matter where the viewer is located within the viewing volume. The y-axis distortion becomes apparent in the corrected hologram as the viewer moves away from the optimal viewing location. Both the x-axis and y-axis distortion become very

Original Perspective views; + 20 degrees, center, and -20 degrees, respectively.



Corrected holographic stereogram; + 20 degrees, center, and -20 degrees, respectively.

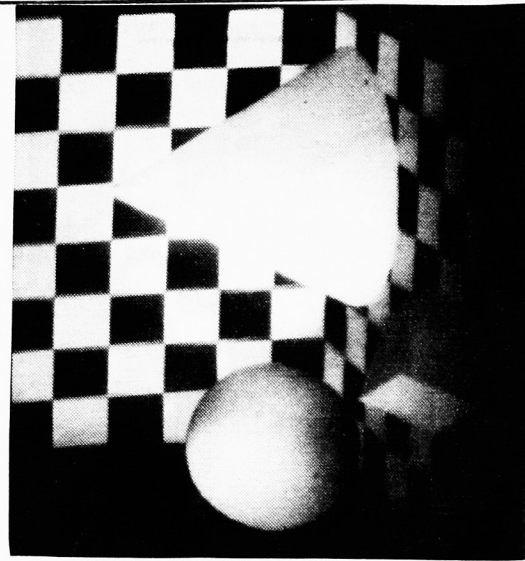
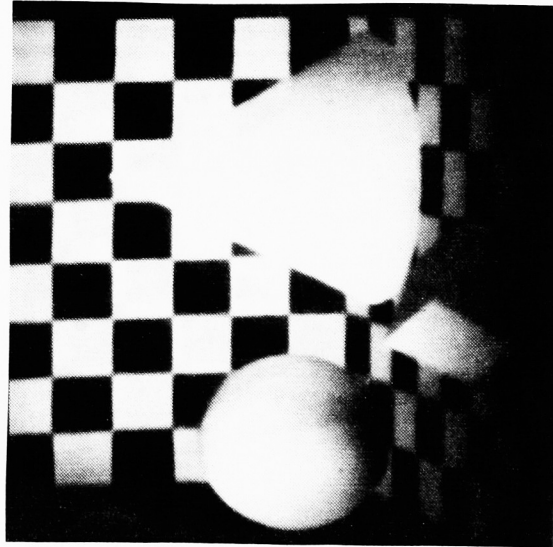
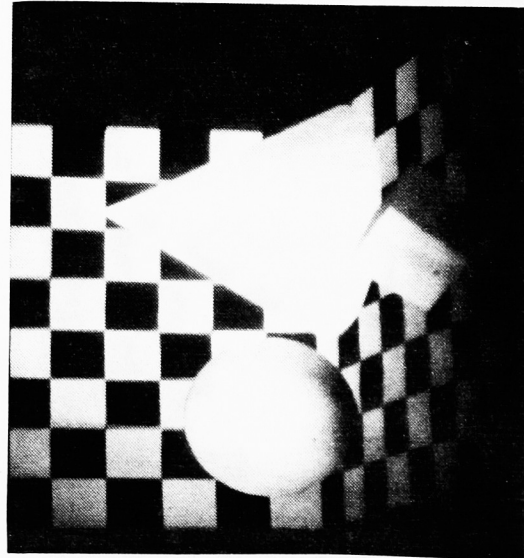
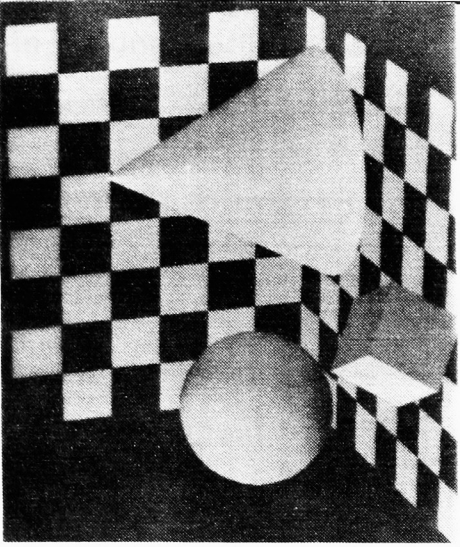
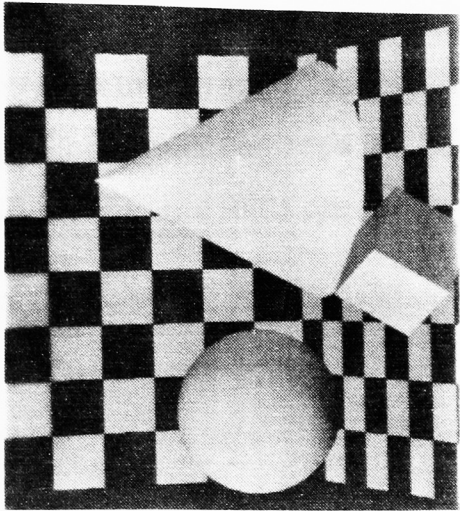
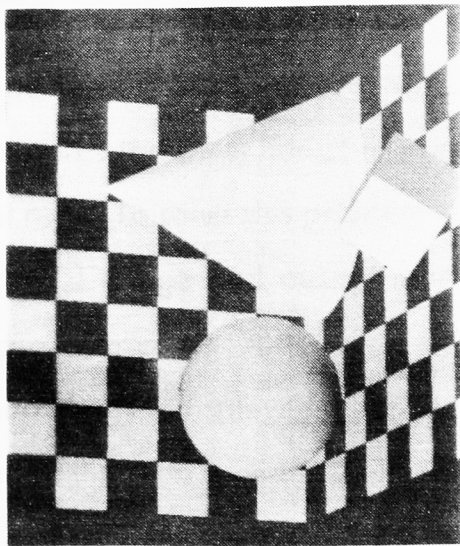


Figure 18

Original Perspective views; + 20 degrees, center, and -20 degrees, respectively.



Uncorrected holographic stereogram; + 20 degrees, center, and -20 degrees, respectively.

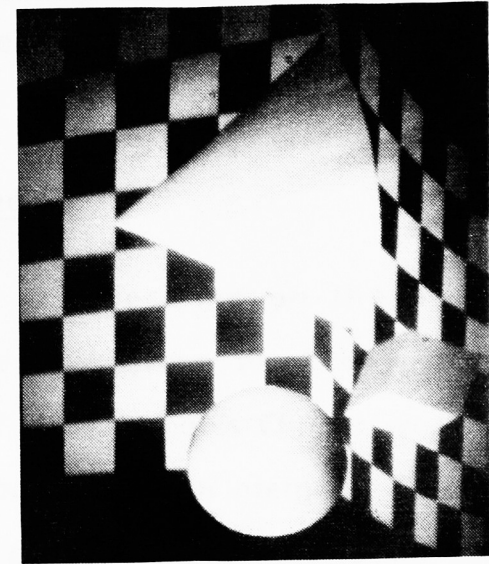
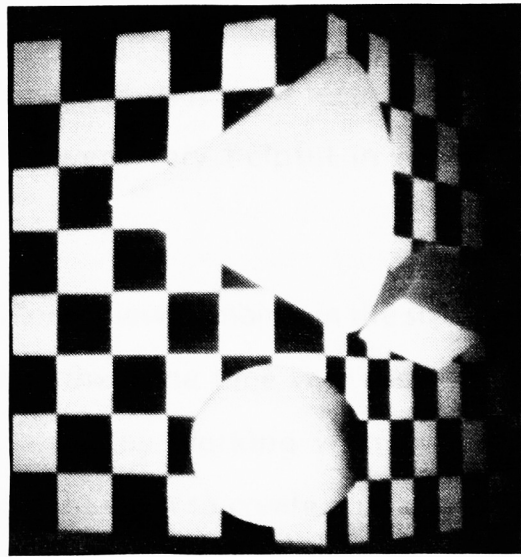
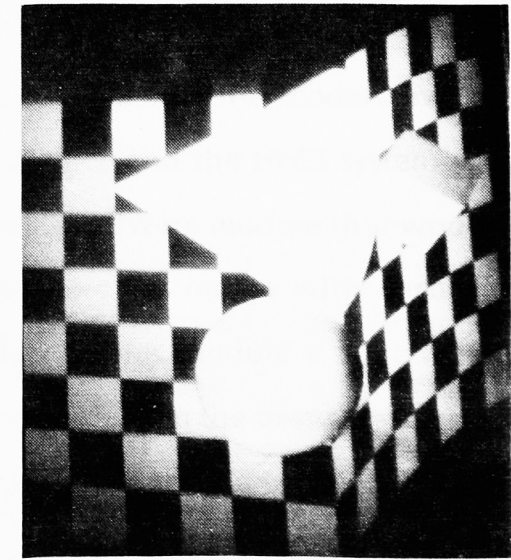


Figure 19

visible in the uncorrected hologram as the viewer moves away from the optimal viewing location.

5.1 Problems Encountered and Solved

The first problem encountered was deciding on the particular hardware/software platform to build the HFGS system on. I chose to do the software development using Intergraph Corporation's Clipper workstation environment because it appeared that I could work with Intergraph Corporation in the specifications for the ModelView product to get some special features added to their product set. As it turned out we have had a very good working relation with Intergraph's ModelView software development team. Specifically George Smith and Cameron Stubbs, who were very helpful in interfacing ModelView with the HFGS system.

The second problem was how to get ModelView to maintain the size, shape, and orientation of the image plane, and at the same time vary the eye point along the eye point vector. This was solved by working with Intergraph Corporation's ModelView product development team to create a unique option in ModelView's Viewfinder module.

The third problem encountered was the fact that the ModelView RLE file format stores the pixel image in horizontal runs, and the HFGS system requires vertical runs. To solve this problem I created a software module that would read the original image and output a modified original image with vertical runs instead of horizontal runs. One side effect of this module is that when the modified image is displayed it appears rotated 90° from the original image. Since the terminal screen is wider than it is high, the corrected images also needed to

be rotated back 90° before photographing. So an additional module, that turns the corrected images back to their correct orientation, was created.

5.2 Current Shortfalls of the HFGS System

The system was designed as a prototype system, intended for use in research into holographic stereograms. Its intended users are researchers who understand the holographic stereogram process and the HFGS system. It was also designed assuming that the users would know IGDS three-dimensional modeling system and how to use the ModelView product. With these assumptions as the ground rules, the software was developed without spending a lot of time in the development of extensive error checking and recovery routines. Each module assumes that the data it needs is correct and available. All errors encountered by the system cause the particular module to terminate.

The HFGS system requires a large amount of disk space. To function effectively in a test environment the system needs 300 - 600 megabytes of disk space. The data storage for the test hologram required 175 megabytes of disk space. If one were either making several holograms at the same time, or a more complex three-dimensional model one could easily use 600 megabytes of disk space.

5.3 The Future and the HFGS System

If the HFGS system were to migrate from a prototype system to a production system there are several things that should be done to streamline the system.

A huge elapsed processing time savings could be recovered by utilizing concurrent processing in the system. It is conceivable that all the modules in the system could run concurrently, passing the images through each module as they

are created, so that the last image is photographed almost immediately after ModelView created it.

The HFGS system could also be modified to allow for the creation of corrected images for other holographic stereogram formats (circular, concave, etc.).

The time and expense associated with photographing the computer images could be saved by using a liquid crystal spatial light modulator[17,18]. If the images are displayed on the spatial light modulator and the object beam is allowed to pass through the spatial light modulator onto the diffuser, slit holograms can be created from the images directly from the computer.

Another interesting extension of the HFGS system is to incorporate full parallax in the corrected images. The major problem associated with implementing full parallax into holographic stereograms is that the processing time and storage requirement grow at an n^2 rate.

An exciting application of holographic stereograms is to combine them with other display techniques to enhance communication to the viewer. This has been demonstrated on information displays on office machines[19,20,21,22]. This approach enhances the viewer's perception of where machine faults are by displaying the fault location with a holographic stereogram coupled with a liquid crystal display.

Possibly one of the most useful applications of computer generated holographic stereograms is medical imaging[23,24]. Geometrically accurate holographic stereograms created from computer aided tomographic x-ray scanner systems (CAT scanners) or similar devices could provide the medical world

with a wealth of additional information about their subject without exploratory examinations.

If one looks at the future of the image reproduction market, it seem logical that the next major step is three-dimensional images. A current example is the December 1988 issue of National Geographic[25], which has full page holograms on the front and back covers. The back cover is a full page advertisement for a major fast food chain. Wouldn't it be nice to open up a catalog and see the merchandise as a full three-dimensional image?

6. References

- 1 D. J. De Bitetto, Applied Optics, **8**, 1740 (1969)
- 2 J. T. McCrickerd, N. George, Appl Phys. Lett., **12**, 10 (1968)
- 3 S. A. Benton, "Photographic Holography", SPIE Proceedings, **39**12-9 (1983).
- 4 S. A. Benton, "A Survey of Holographic Stereograms", SPIE Proceedings, **36**7 15-19 (1982).
- 5 M. C. King, A. M. Noll, D. H. Berry, "A New Approach to Computer-Generated Holography," Applied Optics, **9**-2 471-475 (1970)
- 6 L. Huff, R. L. Fusek, "Application of Holographic Stereograms to Three-Dimensional Data Display", SPIE Proceedings, **36**7 84-92 (1982).
- 7 T. Honda, K. Okada, J Tsujiuchi, "Three-Dimensional Distortion of Observed Images Reconstructed from a Cylindrical Holographic Stereogram. (1) Laser Light Reconstructed Type," Optics Communications, **36**-1 11-16 (1981)
- 8 T. Honda, K. Okada, J Tsujiuchi, "three-dimensional Distortion of Observed Images Reconstructed from a Cylindrical Holographic Stereogram. (2) white Light Reconstructed Type," Optics Communications, **36**-1 17-21 (1981)
- 9 I Glaser, "Anamorphic Imagery in Holographic Stereograms," Optics Communications, **7** 11 (1973)
- 10 P. Hariharan, Optical Holography, Principles, Techniques and Applications, Cambridge University Press (1984).
- 11 E. N. Leith, J Upatnicks, "Photography by Laser", Scientific America 24-35 (June 24, 1965)

- 12 L. Huff, J. S. Loomis, "Three-Dimensional Imaging with Holographic Stereograms", 1983 SPIE International Technical Conference, (April 1983).
- 13 S. M. Jaffey, K. Dutta, "Digital Perspective Correction for Cylindrical Holographic Stereograms", SPIE Proceedings, **367** 130-140 (1982).
- 14 L. Huff, R. L. Fusek, "Optical Techniques for Increasing Image Width in Cylindrical Holographic Stereograms", SPIE Proceedings, **215** 39-45 (1980).
- 15 M. A. Teitel, S. A. Benton, "Anamorphic Imaging for Synthetic Holograms," preprint of paper, Spatial Imaging Group, MIT, Cambridge, Ma.
- 16 M. D. Rainsdon, J. R. Andrews, "An Imaging Model for Holographic Stereograms," SPSE 41st Annual Conference, Arlington, Virginia, May 22-26 (1988) .
- 17 J. R. Andrews, B. Tuttle, M. Rainsdon, R. Damm, K. Thomas, W. E. Haas, "Holographic Stereograms of Computer-Generated Objects using a Liquid Crystal Spatial Light Modulator," First International Symposium on the Industrial Uses of Holography, Oct 25-30, Las Cruces, NM (1987).
- 18 J. R. Andrews, B. Tuttle, M. Rainsdon, R. Damm, K. Thomas, W. E. Haas, "Holographic Stereograms Generated using a Liquid Crystal Spatial Light Modulator," SPIE Proceedings, **902** 92-94 (1988).
- 19 J. R. Andrews, et al., "Compact Illuminators for Transmission Holograms, " SPIE Proceedings, **1051-23** (1989)
- 20 W. E. Haas, J. R. Andrews, M. D. Rainsdon, "Holographic - Liquid Crystal Displays ", SPIE Proceedings, **1051-26** (1989).

- 21 J. R. Andrews, M. D. Rainsdon, W. E. Haas, "Planar Format Holograms having a wide Viewing Angle and Illuminated by a Nearby Point Source," SPIE Proceedings, **1051-32** (1989).
- 22 J. R. Andrews, W. E. Haas, M. D. Rainsdon, "Holographic Display for the Man-Machine Interface," Opt. Eng., **June** (1989) (accepted).
- 23 R. J. Perlmutter, J. W. Goodman, A. Macovski, "Digital Holographic Display of Medical CT Images", SPIE Proceedings, **367** 109-116 (1982).
- 24 K. M. Johnson, L. Hesselink, J. W. Goodman, "Multiple Exposure Holographic Display of CT Medical Data", SPIE Proceedings, **367** 149-154 (1982).
- 25 National Geographic, front and back cover, December (1988)