DESCRIPTION OF A SYSTEM FOR PRODUCING HOLOGRAPHIC STEREOGRAMS

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Abstract

Computer-Aided Holographic Stereography *(CAHS)* is a hybrid technology, which extends the usefulness of the well established technique of stereoscopic photography by applying the relatively new disciplines of holography and computer graphics. In this article, the practical considerations of building a system to produce holographic stereograms are set out. Additionally, it is shown how, using simple microprocessor technology, the system has been automated to the extent that, apart from inputing control parameters via a keyboard, the only human intervention is in handling the holographic film.

Introduction

Computer-Aided Holographic Stereography (CAHS) is a method for producing autostereoscopic (three-dimensional) images from a series of perspective views of a scene, taken from different viewpoints. Its potential use is as a design tool for displaying complex engineering and architectural data as three-dimensional (3-*D*) solid models. The benefit forseen in using such holograms is in their ability to show clearly, and in detail, designs in 3-*D* before the costly and time consuming process of building balsa or plaster models is initiated.

In addition to the monocular depth cues that two-dimensional (2-*D*) images provide e.g. retinal image size and obscuration, 3-*D* images display the following depth cues [1].

a) Stereopsis: the retinal image formed by the right eye, is slightly different from the image formed by the left eye.

b) Changing Parallax: as a viewer moves around the display, the angular relation between objects in the fore and backgrounds will change.

As early as 1838, Wheatstone had devised a method of producing images which displayed stereopsis [2]. The "Wheatstone Stereoscope" consisted of two photographs taken from different directions and directed to the viewer's eyes by a system of mirrors. The stereopair, as they are known, gave the sense of depth and solidity only from one viewing position. To increase the number of positions from which this impression remains intact, and simulate changing parallax, the number of stereopairs must be increased whilst ensuring that each of the disparate views is directed to the correct eye.

The following describes how this is achieved by recording a sequence of perspective drawings as separate rectangular aperture holograms which, together, form a contiguous composite hologram.

Preparation of the perspective drawings used in CAHS

The type of prespective drawing which is used in *CAHS* is referred to as a Central Perspective Projection (CPP). An example of a *CPP* of the point *P*, from viewpoint *V*, is shown in Fig. 1. By constructing *CPP*'s of all points in a scene, it is possible to reduce a 3-*D* scene to a drawing on a 2-*D* plane, which is named the projection plane. For the purpose of *CAHS*, many such drawings of a scene are generated, by computer, from viewpoints whose locus of points describes a circle with centre at the origin of the scene's coordinate framework.

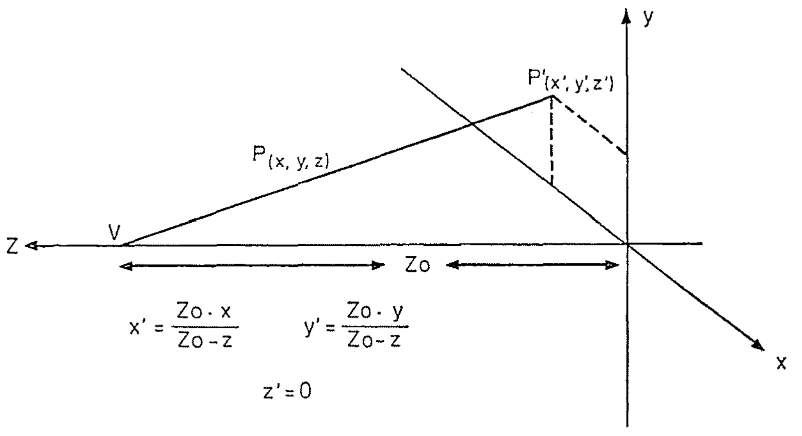
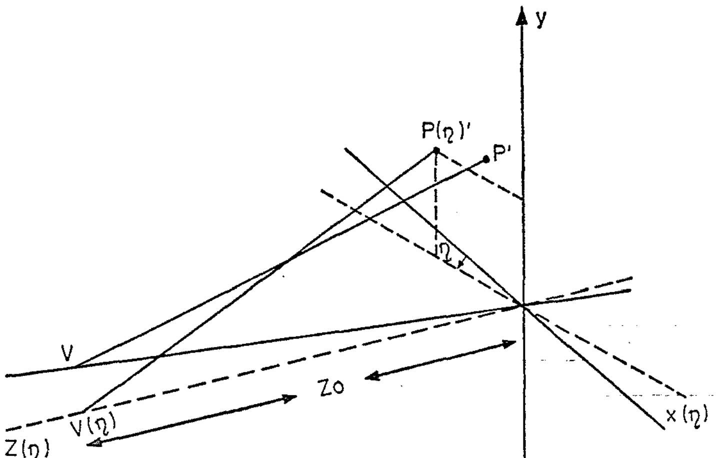


Fig. 1. Construction of a Central Perspective Projection from a Single Viewpoint

Fig. 2. shows the relation between two viewpoints and their shifted *CCP*'s of the stationary point *P*. For input into the *CAHS* system, the set of perspective drawings are displayed individually on the computer monitor and then photographed.

After processing, each photographic transparency is used as a spatial light modulator to produce the object wave of a separate rectangular aperture off-axis laser transmission hologram. The centre of each of the holograms is defined by the position of the viewpoint from which the perspective drawing was created. The separation



$$x(\eta)' = \left[\frac{(x\cos\eta - y\sin\eta)\,Zo}{(x\sin\eta + y\cos\eta - Zo)}\right]$$

$$y(\eta)' = \left[\frac{Z\cdot Zo}{(x\sin\eta - y\cos\eta - Zo)}\right]$$

$$Z(\eta)' = Z' = 0$$

Fig. 2. Construction of Central Perspective Projections of a Stationary Point from two Viewpoints

of the viewpoints, which is the slitwidth of each hologram, is chosen so as to reduce slit to slit discontinuities, or 'flipping', in the final image to a level which cannot be resolved by the eye. From simple calculations involving the resolution of a diffraction limited circular aperture i.e. the human eye [3], it is found that to prevent flipping, in a composite hologram, which is to give a 180° viewing angle, at least 540 elements are required.

The semi-automated recording system

To record a sequence of 540 holograms within a resonable period of time, with consistent results, requires considerable automation. The automation process which is presently under evaluation can be represented by a closed loop flow diagram, as shown in Fig. 3.

The interfacing for control of the individual components of the system, namely electronic shutter, 35 mm. film strip and holographic film transport, is achieved using the userport of a BBC Model B Microcomputer [4].

The slit aperture of the hologram is achieved by pulling a length of 12.7 cm. wide Agfa-Gevaert Holotest film against two curved plates, which form a concave surface when together, but for our purposes are held apart. The bulk of the film is

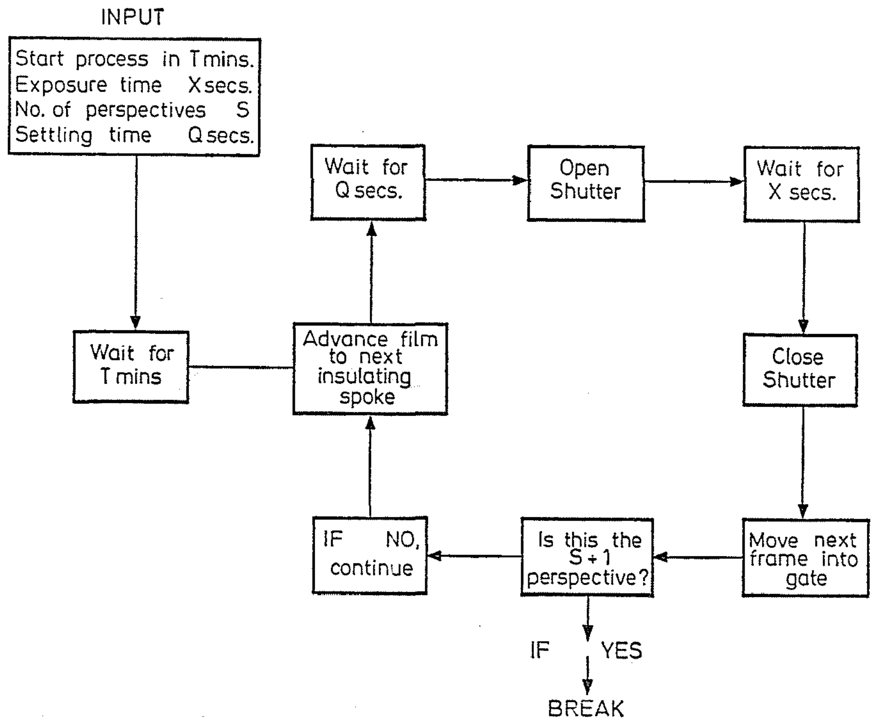


Fig. 3. Flow Chart of Automation Process

initially wrapped tightly around a storage spool and passes over the curved plates, between two pinch-rollers and onto a drive spool. The drive is turned by a wormdrive attached to a four phase hybrid stepper motor. As the film is fed onto the drive spool, it causes the pinch-rollers to turn slowly. The spindle of one of the pinch-rollers has a disc attached with spokes of conducting and insulating material on its lower surface. The spokes are machined so that their separation is equal to a slitwidth linear translation of the film. A +5V potential is applied to a contact on the upper surface of the disc. A stylus, held stationary against the lower surface of the disc, is thus either at +5V or 0V, dependent upon whether it rests on a conducting or insulating spoke. The signal from the stylus is fed to one of the user port pins, which is configured to be an input.

The each four step cycle of the motor, the user port is read and tested to find whether the pin is high or low. A sequence of high to low readings, indicating that the stylus has passed from a conducting to an insulating spoke, interrupts the power to the stepper motor.

The delay routines necessary to control settling and exposure times, were achieved with the use of the built-in computer internal clock. Using the system pseudovariable TIME, it is possible to construct simply delay software with a precision of 1/100 th. sec. [5].

Recording and reconstructing the hologram

The individual components under computer control, as described in the previous section, were implemented as part of a camera for producing holographic stereograms. To isolate the camera from vibrations during exposures, which can smear the fringe structure of the hologram, the camera is secured to an optical table which rests on a set of pneumatic mounts. A diagram of the camera is given in Fig. 4.

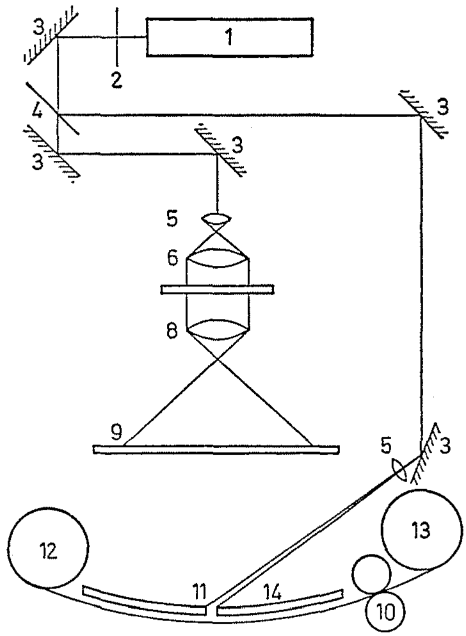


Fig. 4. Diagram of the Holographic Camera

Key to Fig. 4

1: He—Ne laser.
2: Electronic shutter.
3: Front-silvered mirror.
4: Beam splitter.
5: Spatial filter.
6: Collimator.
7: Spatial light modular (LCTV).
8: Imaging lens.
9: Diffuser.
10: Pinch-rollers.
11: Slit.
12: Film reel.
13: Take-up spool.
14: Curved back plate.

The camera was constructed as follows. The beam from a Helium-Neon laser is steered by a front surfaced mirror (FSM) through an electronic shutter and is split by a variable density beam splitter. One portion of the beam is expanded and passes through the perspective drawing transparencies which are stored on the film transport mechanism of a projector. The lens system of the projector forms an image of the perspective drawing on a scatter plate which is positioned a distance Z_0 from the concave backplate. The light scattered from the scatter plate falls onto the rectangular opening in the backplate. In this fashion, the scattered light forms the object beam of a slit aperture off-axis laser transmission hologram [6].

The other portion of the beam is steered upward onto an FMS which is high 0.8 m. above and parallel to the table top. This being the most stable configuration for an overhead reference mirror, as in-plane displacements do not alter the optical beam path. The beam is deflected downward by the mirror and expended, with of virtual source directly above the center of the scatter plate, so that it forms a divergenc reference beam at the slit aperture.

Before initiating the recording process, the operator positions the transparency of the first perspective drawing in the film gate of the projector. The values which determine settling and exposure times are keyed into the computer, as indicated in Fig. 3. After a delay of T minutes, which allows for the flexibility of remote operation, power to the stepper motor is activated and then switched off automatically when the pinch-roller stylus reaches an insulating spoke. This is to ensure that the next transport of the holographic film is a whole slitwidth.

To allow mechanical vibrations from the motor to fade there is a Q seconds wait before the shutter is opened. The light now passes through the system forming a standing wave in the vicinity of the rectangular aperture. The interference pattern, thus formed, causes variations in exposure of the emulsion of the slit hologram which when processed, produce the grating like structure of the hologram. The shutter closes after X seconds and the 35 mm film strip is moved to the next frame by a stepper motor attached to the winding mechanism of the projector. This "loop" is self sustaining until at the $S+1$ loop, the software jumps out.

The length of exposed film is developed in Kodak D19 at 19 ± 1 °C for 5 minutes (with $X=8$) to a density of 0.7. After fixing, the film is bleached clear in a bath of potassium bromide bleach. The film is washed, dried and joined to a length of clear film so that when joined end to end, the whole film forms a cylinder radius Z_0. The additional "dummy" film is necessary in this case because we have recorded a hologram with only a 180° viewing angle.

The surface that was closer to the laser source in the recording stage should be the inner face of the cylinder. The reconstructing source is positioned on the central vertical axis of the cylinder at a height equal to that of the original reference beam and, ideally, with the same divergence.

Results and discussion

Several holographic stereograms, with limited viewing angle, have been produced using the system described. The subject chosen for the hologram was a wireframe cube, as this is relatively simple to describe with a 3-D data set of points defining its corners. A graphics program for producing the perspective drawings of the cube was written in BASIC.

When viewed from a distance equal to that suggested in the foregoing, the holograms do not suffer from flipping. However, if viewed at a much closer distance, the effect of parallax quantization can become marked.

Inherent in this type of holographic stereogram is a form of distortion called anamorphic distortion. This can be understood by remembering that each slit hologram is effectively a window to a single perspective drawing. Hence, a viewer looking at different heights along the slit's length will experience no change in parallax. However, as a consequence of the slit structure of the hologram, there is horizontal parallax. This leads to the anamorphotic effect of different amounts of magnification in the horizontal and vertical planes [7]. The effect can be ameliorated, at the cost of increased computing and recording times, by generating a 2-*D* matrix array of hologram elements.

Conclusion

Some of the practical details involved in building a camera for the production of holographic stereograms are presented. A schematic diagram for the system control software, which responds to operator input of exposure parameters, is given.

The holograms, as described, are reconstructed with a laser source. With an additional imaging step they can be made viewable in white light [8]. Whilst the system, as it stands, does generate pleasing holograms, the length of production time seriously limits its applications. The use of film as the spatial light modulator, which has been identified as the major bottleneck, can be substituted by an electrically addressable dynamic scattering liquid crystal storage device.

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